PALEOECOLOGY AND SEDIMENTOLOGY OF MIDDLE DEVONIAN SHORT-TERM SEALEVEL FLUCTUATIONS RECORDED WITHIN THE WANAKAH SHALE MEMBER OF WESTERN NEW YORK

KEITH B. MILLER
Department of Earth Science
Clemson University
Clemson, South Carolina 29634

INTRODUCTION

The fine-grained sediments of the Middle Devonian Hamilton Group, deposited within the northern tongue of the storm-dominated Appalachian Basin, have proven to be an excellent testing ground for many paleoecologic and stratigraphic concepts as demonstrated by many past NYSGA guidebook articles. The extensive stream and lake shore outcrop exposures, relatively undisturbed "layer cake" stratigraphy, and well-preserved benthic faunas of the Hamilton Group in western and central New York are ideal for detailed sedimentologic, paleontologic, and taphonomic studies. Such studies have begun to uncover the wealth of information contained within the superficially homogeneous mudrocks and thin limestones of the Hamilton Group.

Fossil taphonomy is an important, if not vital, source of data for the interpretation of depositional environments, particularly within fine-grained rocks lacking obvious sedimentary structures. The relative effects of the post-mortem processes of reorientation, disarticulation, fragmentation, corrasion and encrustation upon various skeletal materials yields considerable information on rates of burial, exposure time, and degree of physical reworking (Brett & Baird, 1986a). Comparison of these taphonomic features from bed to bed or outcrop to outcrop enables subtle environmental gradients to be discerned (Norris, 1986).

As attention has been drawn to the details of individual shell beds, their storm-event origins have increasingly been recognized in shallow shelf settings. Using individual storm event-beds as building blocks, a temporal hierarchy of physical processes and biological responses can be reconstructed, from the scale of single beds to the ordering of facies sequences within an entire depositional basin (Aigner, 1984, 1985). Internally, shell beds record the complex short-term interactions of episodic storm-generated physical disturbance, substrate consistency, and benthic community composition (Miller, *et al.*, 1988). Onshore-offshore gradients in the relative frequency, sedimentologic character and fossil taphonomy of storm beds enables relative water depths to be determined (Brett *et al.*, 1986a). In addition, widely traceable storm event-beds or packages of event beds possessing distinctive taphonomic and faunal signatures can be used as isochronous markers for very high-resolution correlation. At a yet greater temporal scale, cyclic patterns in the taphonomy and faunal composition of shell beds reflect sea-level fluctuations at several temporal scales (Savarese *et al.*, 1986; Brett and Baird, 1986b; Miller, in press). These cycles afford a potentially valuable means for correlation since the positions of maximum regression and transgression provide basinwide isochronous markers. The character of these cycles also provides a very important clue to the dynamics of deposition within the northern Appalachian Basin during the Middle Devonian.

STRATIGRAPHIC AND PALEOGEOGRAPHIC SETTING

The general basin paleogeography and tectonic setting of the northern Appalachian Basin during the deposition of the Middle Devonian (Givetian) Hamilton Group is now fairly well known (Fig. 1). The Appalachian Basin was characterized by a western carbonate margin and an eastern siliciclastic margin for most of the Paleozoic (Cotter, 1983; Read, 1980; Walker *et al.*, 1983; Brett and Baird, 1985). During the Givetian the western New York area was occupied by a muddy carbonate ramp with a very gentle paleoslope (<< 1°) dipping south to southeastward toward the basin center. The basin axis trended approximately northeast to southwest and was centered in the Seneca and Cayuga Lake area, with a somewhat steeper clastic slope to the east (Baird, 1981; Brett *et al.*, 1986b). A silty and sandy platform then extended eastward to a prograding "deltaic" shoreline in the vicinity of present day Albany (Dennison, 1985). This clastic progradation represents the first influx of sediment from the initial pulses of the Acadian Orogeny.

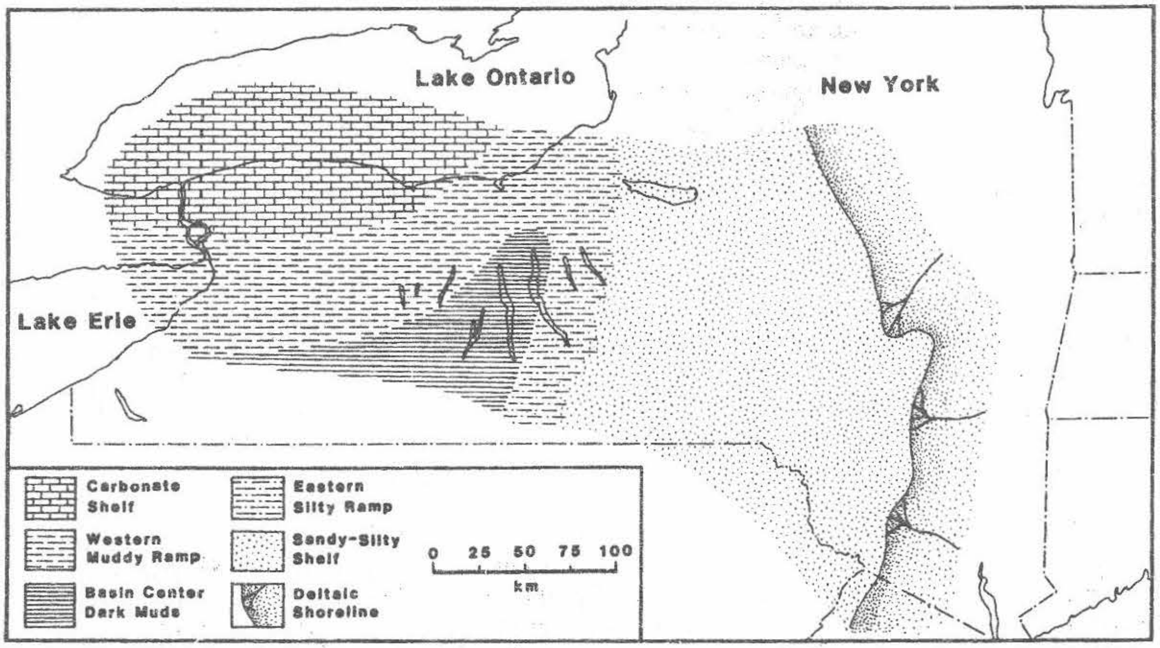

Figure 1. Paleogeographic reconstruction of the northern Appalachian Basin during deposition of the Wanakah shales. Note the nearly E-W depositional strike of the muddy carbonate ramp in western New York State.

The generally fine-grained sediments of the Hamilton Group have been subdivided at the formational level on the basis of very widespread carbonate units such as the Stafford, Centerfield, and Tichenor Limestones (see Fig. 2). Member and submember boundaries are likewise marked by widely persistent thin shelly carbonate beds or diastemic horizons which contain taphonomic and sedimentologic evidence of significant stratigraphic condensation. These diagnostic condensed beds, therefore, delineate clearly defined, bounded units of regional extent within which the detailed correlation of numerous shell-rich horizons can be attempted. One such bounded interval, and the focus of the following discussion, is the lower Wanakah Member of the Ludlowville Formation in western New York, recently named the Darien Center Submember (Brett *et al.*, 1986b).

DESCRIPTION OF DARIEN CENTER SUBMEMBER

Lithologic and Faunal Description of Internal Units

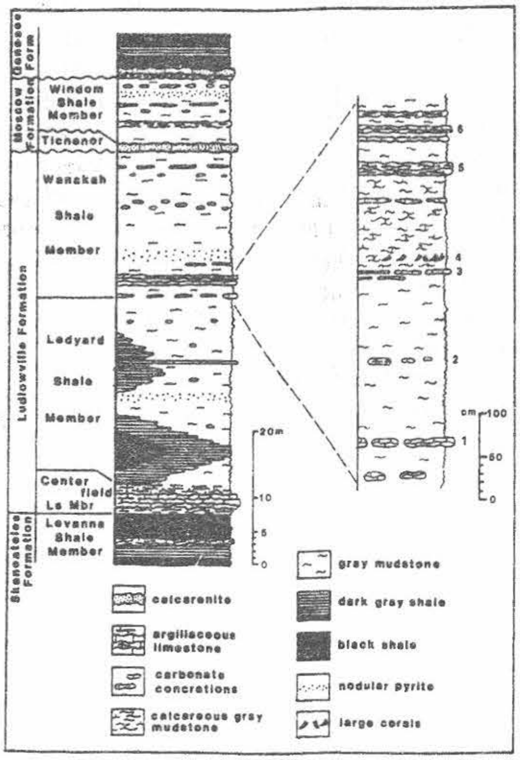

Figure 2. General stratigraphic column for the Ludlowville and Moscow Formations of the Hamilton Group in Erie County, western New York. The Darien Center Submember of the Wanakah Shale Member, which is the focus of this paper, is shown in detail to the right. Beds widely traceable throughout western and central New York designated by numbers as follows: 1) Mt. Vernon Bed marking base of Wanakah Member, 2) Girdle Road Bed, 3) Lakeview (*Nautilus*) Bed, 4) Darien Coral Bed, 5) Murder Creek (trilobite) Bed, and 6) Bidwell (trilobite) Bed. Descriptions of beds can be found in Kloc (1983) and Miller (in press). Figure modified from Brett *et al.*,1986b.

The Wanakah Member of the Ludlowville Formation in western and central New York State is ideal for studying cyclic and event processes. It is a thin sequence of gray calcareous shales and thin argillaceous limestones and concretionary layers. Fossils are concentrated in centimeter-thick layers separated by poorly fossiliferous to barren shales. Of the numerous persistent shell layers and fossil-rich calcareous beds, several have long been recognized as widely traceable stratigraphic markers with characteristic faunas (Grabau, 1899; Cooper, 1930). Cooper (p.225) defined the base of the Wanakah by one such bed, the "*Strophalosia* Bed" (renamed the Mt. Vernon Bed by Kloc, 1983), which can be recognized from Lake Erie as far as the Owasco Valley (Brett *et al.*, 1986b). The sedimentary package discussed herein extends upward from this prominent key bed to include the widespread lower Wanakah "Trilobite Beds" of Grabau (1899, p.40-41). Two of these beds, the Murder Creek and Bidwell Beds (Kloc, 1983), are traceable from Lake Erie at least to the Seneca Valley, a distance of over 150 km. The well-defined, thin (3-5 meter), stratigraphic interval bounded by the Mt. Vernon and Bidwell Beds has been named the Darien Center Submember (Brett *et al.*, 1986b; Miller, in press) (see Fig. 2). The designated type section for the Darien Center Submember is the stream bank exposure along Elevenmile Creek within Darien Lakes State Park near the town of Darien Center.

The **Mt. Vernon Bed** is a thin (~10-15 cm thick) argillaceous limestone typically containing the small productid brachiopod *Truncalosia truncata*, previously referred to as *Strophalosia truncata*. In addition to *Truncalosia*, the Mt. Vernon bed is characterized by an abundance of

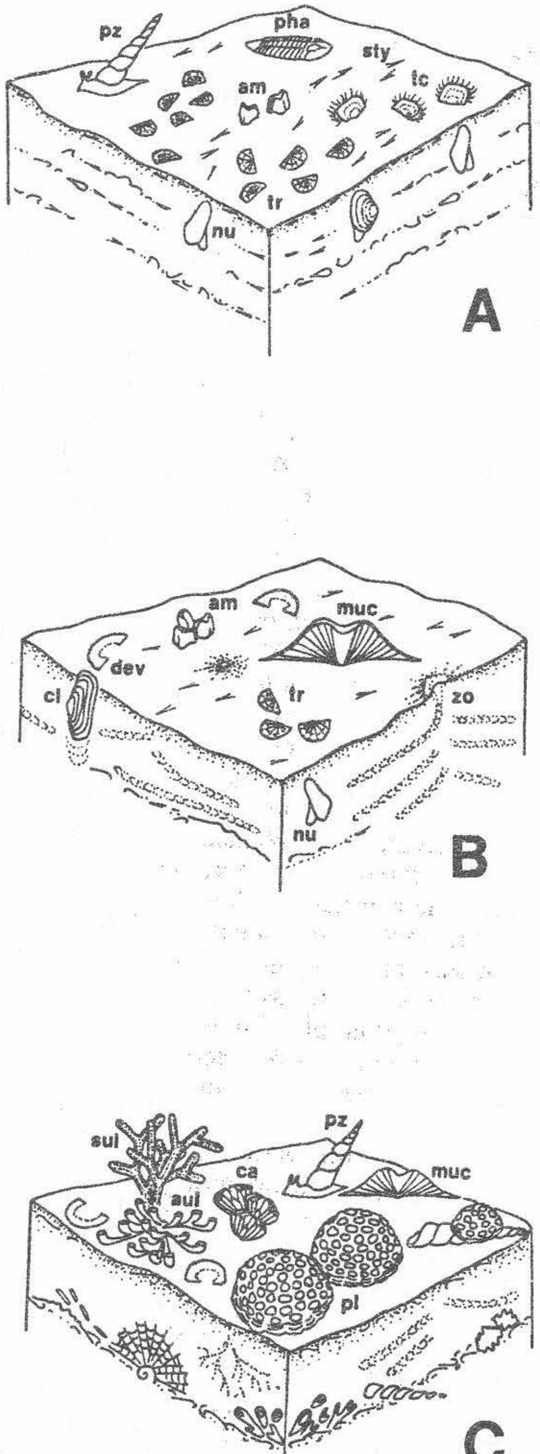

Figure 3. Schematic block diagrams illustrating characteristic benthic faunal assemblages and event bed appearance of key-bed-bounded intervals. A) Diminutive Brachiopod Assemblage of the Mt. Vernon Bed. Closely spaced shelly pavements are typical of this bed and the shales below. B) Very low diversity Chonetid-nuculid Assemblage characteristic of the interval between the Stolle Road and Girdle Road Beds. *Zoophycos* spreiten are abundant and shell pavements are rare. C) *Camarotoechia* Assemblage between the Girdle Road and Lakeview Beds characterized by abundant *Pleurodictyum* corals. Pavements of chonetids and winnowed crinoidal layers are colonized by moderately diverse epifaunal assemblage. Fossil abreviations are as follows: (am) *Ambocoelia*, (tc) *Truncalosia*, (tr) *Tropidoleptus*, (dev) *Devonochonetes*, (muc) *Mucrospirifer*, (ca) *Camarotoechia*, (sty) *Styliolina*, (pz) *Palaeozygopleura*, (nu) nuculid, (cl) *Cypricardella*, (aul) *Aulocystis*, (pl) *Pleurodictyum*, (sul) *Sulcoretepora*, (pha) *Phacops*, (zo) *Zoophycos*..

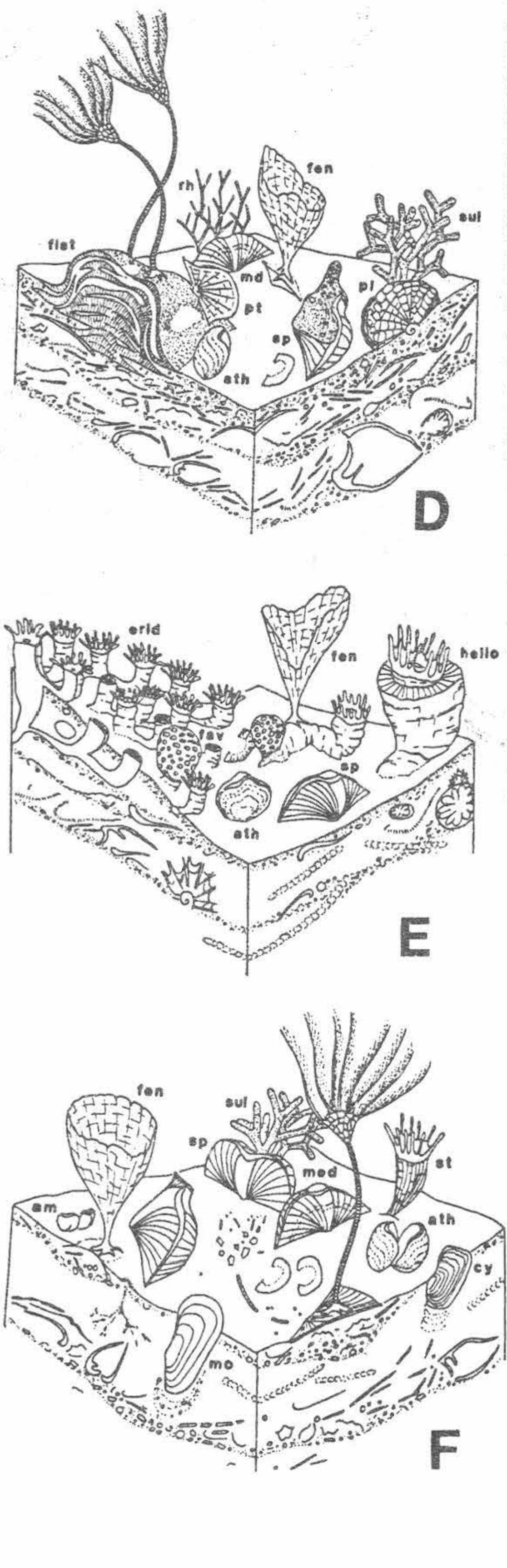

Figure 3 (cont'd). D) Diverse Brachiopod Assemblage characteristic of the Lakeview Bed and the central portion of the Darien Center Submember. Note dominance and variety of bryozoans, and the large spiriferid brachiopods. Epifaunal pectinid and pterioid bivalves are particularly common. Event beds are amalgamated into complex beds recording multiple winnowing and colonization events. E) Heliophyllum Assemblage of the Darien Coral Bed. Note *Eridophyllum* colony with multiple internal trapped mud layers, and geniculated *Heliophyllum* coral developed in response to toppling and regrowth. Small favositid coral colonies grow on dead coralites. F) Diverse Brachiopod Assemblage of the Fargo Bed with life-position clusters of large spiriferid brachiopods. Event beds show sharp, scoured bases with finely comminuted shell debris and crinoid ossicles, and smothered tops with unfragmented, articulated, and often life-position fossils. Fossil abbreviations are as follows: (am) *Ambocoelia*, (dev) *Devonochonetes*, (md) *Mediospirifer*, (ath) *Athyris*, (sp) *Spinocyrtia*, (cy) *Cypricardinia*, (mo) *Modiomorpha*, (pt) *Pterinopectin*, (pl) *Pleurodictyum*, (st) *Stereolasma*, (helio) *Heliophyllum*, (erid) *Eridophyllum*, (fav) *Favosites*, (sul) *Sulcoretepora*, (rh) *Rhombipora*, (fen) fenestrate bryozoan, (fist) fistuliporoid bryozoan.

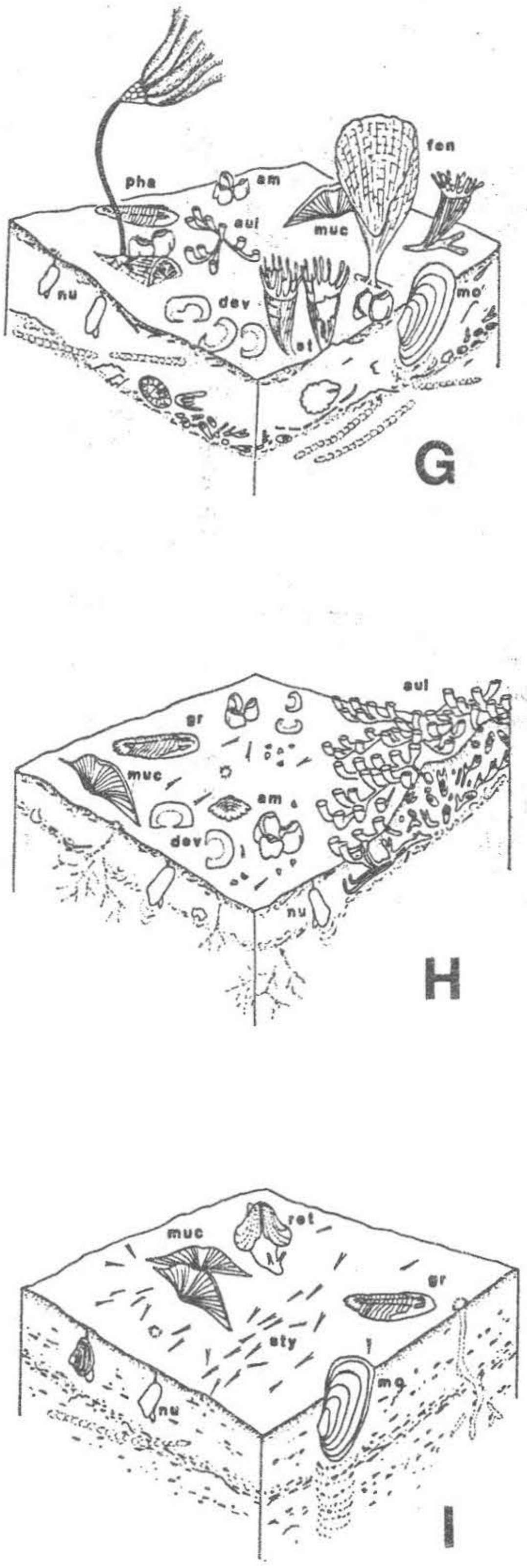

Figure 3 (cont-d). G) *Athyris* Assemblage characteristic of the interval around the Murder Creek Bed. Moderately diverse assemblage of small, usually clustered, brachiopods and auloporid corals with associated cryptostome bryozoans and crinoids. *Phacops* and *Greenops* trilobites are common and frequently occur as enrolled specimens. Note thin, locally discontinuous, fossil horizons with *in situ* articulated fossils. H) *Ambocoelia*-chonetid Assemblage with small ubiquitous brachiopods and mats of auloporid corals. Thin, closely spaced bedding plane concentrations of largely disarticulated skeletal material with fine *Chondrites* burrows. I) Chonetid-nuculid Assemblage of the Bidwell Bed with low-diversity fauna and high concentration of pelagic styliolinids. Fossil abreviations are as follows: (am) *Ambocoelia*, (dev) *Devonochonetes*, (muc) *Mucrospirifer*, (sty) *Styliolina*, (ret) *Retispira*, (nu) nuculid, (mo) *Modiomorpha*, (aul) *Aulocystis*, (st) *Stereolasma*, (fen) fenestrate bryozoan, (gr) *Greenops*, (pha) *Phacops*.

pelagic styliolinids together with orthoconic nautiloid cephalopods, the gastropods *Palaeozygopleura hamiltoniae* and *Retispira leda*, and the unusually small brachiopods *Ambocoelia* cf. *nana*, *Devonochonetes scitulus*, and minute individuals of *Tropidoleptus carinatus* (see Fig. 3A). This faunal assemblage is equivalent to the "Diminutive Brachiopod" assemblage defined by Brett and others (1986, in press). This fauna probably reflects dysaerobic conditions at the sea floor.

Overlying the Mt. Vernon Bed is a peculiar undulatory concretionary horizon which is particularly well displayed along Buffalo Creek, and will be discussed in detail later. The large ellipsoidal concretions of this bed mark a wavy surface which rises over irregularly-spaced lenticular bodies of nearly barren blue-gray shale, but between them becomes welded to the top of the Mt. Vernon Bed. This bed will be hereafter referred to as the **Stolle Road Bed** for its bedding plane exposure on the floor of Buffalo Creek near Stolle Road. Where it is welded onto the Mt. Vernon Bed, the Stolle Road Bed is characterized by dense accumulations of tiny *Ambocoelia* cf. *nana* brachiopods and styliolinids, together with orthoconic nautiloids, palaeozygopleurid gastropods, diminutive individuals of *Devonochonetes* and *Tropidoleptus*, and *Mucrospirifer mucronatus*. An unusual feature of these *Ambocoelia* -rich portions of the bed is the occurrence of 10 cm-wide branching concretionary bodies up to a meter in length (Miller,1986). Resembling large horizontal burrow structures, these concretions have typically high angles of branching which range up to 90°. Their randomness of orientation, which excludes an interpretation as diagenetically enhanced gutter casts, and their relatively uniform width would also seem to suggest a biological rather than physical origin.

As the Stolle Road Bed is traced up the sides of the barren shale lenses, it thins and progressively loses many of its faunal components and becomes increasingly pyrite rich. The tiny ambocoeliid brachiopods are the first to drop out as the shell bed rises from the Mt. Vernon Bed. The diminutive *Tropidoleptus* brachiopods also rapidly decline in number, and *Mucrospirifer* and *Devonochonetes* become the dominant brachiopods within a thin styliolinid hash. Near the top of the lenses, this shelly styliolinid-rich horizon is replaced by an indistinct interval of pyrite nodules and pyritic burrow tubes. The ellipsoidal carbonate concretions which outline the barren shale lenses at the outcrop tend to occur several centimeters below the undulatory shelly and pyritic layer. These concretions appear to be nearly barren of fossils except in the few places where the shelly layer passes through their tops.

Above the undulatory Stolle Road Bed, shell beds are essentially flat-lying. The first traceable shelly horizon is a widespread bed containing a moderately diverse fauna. Recognizable throughout western New York, this shell bed is here named the **Girdle Road Bed** for its exposure along the banks of Buffalo Creek next to the Girdle Road bridge. It marks a pronounced sedimentologic and faunal change from fossil-poor gray shales below to fossiliferous gray calcareous shales above. *Zoophycos* spreiten are particularly common within the fossil-poor shales. Laterally restricted fossil pavements are present, however, and within these pavements, and scattered widely throughout the shale, is a very low diversity faunal assemblage including *Mucrospirifer*, *Devonochonetes*, *Styliolina*, and the trilobite *Phacops rana* (see Fig. 3B). This assemblage is equivalent to the "Chonetid-nuculid" Assemblage defined by Brett and others (1986, in press).

The Girdle Road Bed marks the first occurrence of the discoid tabulate coral *Pleurodictyum americanum* above the Mt. Vernon Bed. Commonly occurring within this distinctive bed are the corals *Stereolasma* and *Aulocystis*, the brachiopods *Athyris*, *Spinocyrtia*, *Protoleptostrophia*, and *Megastrophia*, the trilobites *Phacops* and *Greenops*, as well as crinoids and ramose cryptostome bryozoans. The interval above this bed is equivalent to the

"*Pleurodictyum* beds" recognized by early workers (Grabau 1899, p.58; Cooper,1930, p.225), and has a slightly less diverse fauna than the Girdle Road Bed. In addition to *Pleurodictyum,* the most common faunal elements of this interval are auloporid and stereolasmatid corals, the brachiopods *Devonochonetes*, *Ambocoelia*, and *Camarotoechia*, and nuculid bivalves (see Fig. 3C). The secondarily occupied shells of *Palaeozygopleura* were the preferred attachment sites for *Pleurodictyum* (Brett and Cottrell, 1982), and this gastropod is invariably present, often in abundance. This assemblage is here designated the "*Camarotoechia* Assemblage," and is equivalent to part of the "Mucrospirifer-chonetid" Assemblage of Brett and others (1986, in press). Shell beds within this interval range from thin shelly pavements to beds with scoured bases and basal winnowed layers of crinoid ossicles and shell hash. Within many beds, small individuals of *Devonochonetes* form a basal layer upon which a more diverse fauna was developed. Auloporid corals commonly occcur in thickets or mounds built on shell pavements.

The next prominent concretionary horizon above the Girdle Road Bed overprints a complex amalgamated (multi-event) shell bed at the base of a very fossiliferous interval of gray calcareous shale. I have suggested (Miller, in press) that this bed, named the "*Nautilus* Bed" by Grabau (1899), be renamed the **Lakeview Bed** for its excellent exposure along the Lake Erie shore near the town of Lakeview. The fauna of this bed and the overlying shell beds is highly diverse. Brachiopods include *Mucrospirifer*, *Mediospirifer*, *Spinocyrtia*, *Athyris*, *Rhipidomella*, *Devonochonetes* and *Megastrophia*. The large *Spinocyrtia* brachiopods typically are heavily encrusted with auloporid corals and trepostome bryozoans. The semi-infaunal bivalves *Modiomorpha*, *Cypricardella*, and *Cypricardinia* are common elements, along with the pectins *Pterinopectin* and *Pseudoviculopectin*, and the pterioid *Actinopteria*. To the trilobites *Phacops* and *Greenops* is added the large phacopid, *Dipleura*. A very rich and diverse bryozoan assemblage is present, including fistuliporoids, branching and massive trepostomes, fenestrates, and cryptostomes. Hemispherical fistuliporoid mounds up to 20 cm or more in diameter are particularly characteristic of the shales overlying the Lakeview Bed. Crinoid ossicles are ubiquitous and are typically the primary component of the basal winnowed lags of the shell beds. The *Pleurodictyum* corals are replaced in abundance by *Stereolasma*, and auloporids remain a major component of the fauna. This assemblage, illustrated in Fig. 3D, is equivalent to the "*Pseudoatrypa* (Diverse Brachiopod)" Assemblage of Brett and others (1986, in press).

Within this highly fossiliferous interval, individual fossil layers typically consist of finely comminuted shell debris and disarticulated, often abraded, crinoid ossicles at the base, overlain by diverse epifaunal assemblages with abundant bryozoans. Sharp scoured bases, which commonly have elongate fossil-hash-filled prods similar to gutter casts, cut into underlying shales and may locally intersect older fossiliferous layers. Fossils on the upper bed surfaces are commonly *in situ* and often in life position. Complete articulated crinoids occur within immediately overlying shales, and may be found still anchored to the shell bed below. The significance of this preservational contrast between the bases and tops of shell beds is discussed in detail elswhere (Parsons *et al.*, 1986; Miller *et al.*, 1988).

At several localities in western New York a coral bed is present just above the Lakeview Bed. It varies from a bed of scattered large solitary corals to a nearly continuous 15 cm-thick biostrome of solitary and branching colonial forms. Kloc (1983) has named this thin coral-rich unit the **Darien Coral Bed** for exposures near the town of Darien where the biostromal bed is best developed. The large solitary rugosan *Heliophyllum halli* predominates in the beds of scattered corals, while the branching colonial rugosan *Eridophyllum* dominates the biostromal beds. Other elements of the coral fauna include the solitary rugosans *Cystiphylloides* and

Stereolasma, the branching tabulate *Trachypora*, as well as *Pleurodictyum* and several species of *Favosites*. Associated brachiopods include *Tropidoleptus*, *Mucrospirifer*, *Mediospirifer*, *Spinocyrtia*, *Athyris*, *Devonochonetes*, and *Megastrophia*. Crinoids and bryozoans, particularly fenestrates, continue to be important elements of the fauna. This bed, illustrated in Fig. 3E, represents the "*Pentamerella-Heliophyllum*" Assemblage of Brett and others (1986, in press). Solitary corals typically show geniculated and rejuvenated coralla, and broad conical forms are often found in inverted, calyx-down positions. Branching coral colonies show multiple internal levels of burial, corrosion, and rejuvenation. Corroded coral fragments are common, especially in the upper portion of the coral bed.

The diverse fauna characteristic of the Lakeview Bed continues upward above the Darien Coral Bed to a thin persistent calcareous bed called the **Fargo Bed** by Kloc (1983). The Fargo Bed and the shales immediately above and below are characterized by the presence of large articulated brachiopods, particularly *Athyris*, *Mediospirifer*, and *Spinocyrtia*, which often occur in small clusters of life-position individuals (see Fig. 3F). Within this interval, fossil layers with sharp scoured bases are separated by 4-6 cm of fossil-poor shale containing bivalves such as *Modiomorpha* and *Cypricardinia*. The fauna of the shell beds above the Darien Coral Bed differs little from that of the Lakeview Bed.

Above the Fargo Bed is a widely traceable prominent diagenetic carbonate bed containing abundant trilobites, which are often preserved in enrolled positions. This lowest of Grabau's (1899) "Trilobite Beds" has since been called the **Murder Creek Bed** (Kloc, 1983). Discontinuous thin fossil layers with a moderately diverse epifaunal assemblage are separated by fossil-poor shales a few centimeters thick. The highly abundant tiny spiriferid *Ambocoelia*, and the strophomenids *Pholidostrophia*, *Douvillina*, and *Devonochonetes* are the characteristic brachiopods of this interval. Though absent within the Murder Creek Bed, abundant *Athyris* occurs in a widely traceable horizon a few centimeters above. The trilobites *Phacops* and *Greenops*, and the corals *Aulocystis* and *Stereolasma* are all abundant components of the fossil horizons. Modiomorpha and nuculid bivalves occur as common elements of the low-diversity fauna between the shelly layers. This assemblage (see Fig. 3G) is essentially equivalent to the "*Athyris*" Assemblage of Brett and others (1986, in press).

Significant faunal and taphonomic changes occur above the *Athyris*-rich horizon mentioned above. Here, closely spaced horizons or pavements of finely fragmented brachiopod debris, ostracods, and styliolinids are characteristic. Within these horizons are patches of disarticulated *Greenops* trilobites, and disarticulated valves of *Mucrospirifer*, *Devonochonetes*, and *Ambocoelia*. The auloporid coral *Aulocystis* is common, and occurs as small *in situ* patches, or at some localities as irregular mats up to 3 cm thick. A few small *Stereolasma* are associated with these mats, some of which still have apices attached to the auloporids. Iluustrated in Fig. 3H, this assemblage is the "*Ambocoelia*-chonetid" Assemblage of Brett and others (1986, in press).

Lastly, the top of the Darien Center Submember is marked by a very prominent carbonate bed which has been named the **Bidwell Bed** (Kloc, 1983). This highly condensed bed contains thin graded styliolinid layers with disarticulated *Greenops* trilobites and *Mucrospirifer* and *Devonochonetes* brachiopods. The nuculid bivalve *Paleoneilo*, semi-infaunal bivalves *Modiomorpha* and *Modiella*, and the archeogastropod *Retispira* are characteristic of this bed. Burrowing is extensive, with *Zoophycus* spreiten, vertical burrows up to 1.5 cm in diameter, and fine *Chondrites* burrows. The fauna of this bed (see Fig. 3I) would fall within the "Chonetid- nuculid" Assemblage.

Correlation Across Western New York

The key shell beds described above, and the intervals which they bound, are remarkable in their persistence over western New York for lateral distances exceeding 100 km. The vertical sequence of distinctive key beds and the vertical faunal and taphonomic patterns have proven to be so consistent that they can be used in a predictive fashion from outcrop to outcrop, thus greatly improving confidence in the accuracy of field correlation. This lateral uniformity is especially significant in light of the very thin stratigraphic intervals involved, with individual key-bed-bounded units only decimeters thick. The correlation of these internal units of the Darien Center Submember among ten measured and sampled sections is shown in Fig. 4, and illustrates the amazing "layer cake" stratigraphic pattern present.

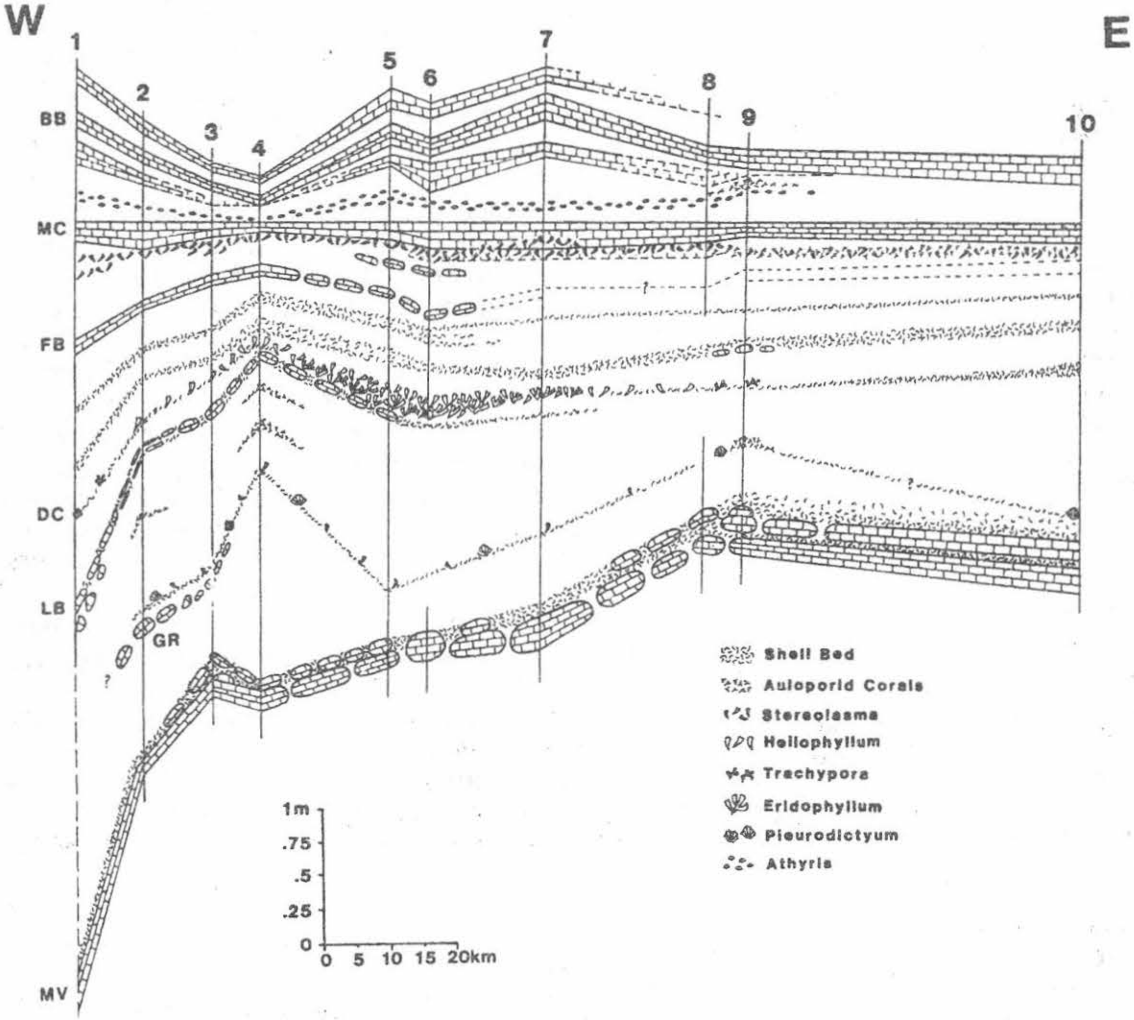

Figure 4. Correlated stratigraphic sections of Darien Center Submember showing position of widely traceable key beds, and drawn with Murder Creek Bed as datum. Numbered localities are as follows: 1) Lake Erie Shore, 2) Rush Creek, 3) Cazenovia Creek, 4) Buffalo Creek, 5) Elevenmile Creek, 6) Murder Creek, 7) Francis Road railroad cut, 8) Salt (Bidwell) Creek, 9) Wheeler Gully, and 10) Hopewell Gully.

The numerous closely spaced key beds function as very high-resolution correlation lines across western New York. Not only do they provide important marker beds within the thin, laterally uniform western facies, but they have also been subsequently traced across the substantial thickness and lithofacies transitions of the basin axis in the Seneca and Cayuga Lake valleys (see Fig. 1). Individual key beds can be traced from the western calcareous shales into the silty mudstones of the basin axis, and even into the hummocky cross-stratified siltstone and fine sandstone on the eastern side of the basin axis (Brett *et al.*, 1986b). Such facies independence suggests that these beds, each composed of several superimposed and amalgamated event horizons, may represent time lines and thus have important chronostratigraphic utility.

Several lines of argument can be made for the isochroneity of the key beds described above (a detailed discussion of these arguments can be found in Miller, in press). 1) When traced across the basin they can be seen to clearly cross-cut facies. The close parallel of key beds and facies units within western New York is an artifact of the near coincidence of the trend of the ourcrop belt and depositional strike. However, across the basin axis to the east, they show substantial internal lithologic, taphonomic, and faunal change (Miller, 1988). The genesis of these beds was therefore independent of specific depositional environments. 2) Most key beds are overprinted by very early diagenetic limestones and concretionary layers which may record chemical responses to specific sedimentation events. The rapid burial of long-term shelly accumulations, and the living communities colonizing them, by storm-redeposited mud could catalyze widespread concretion formation (Berner, 1968). 3) The commonly scoured basal surfaces of individual shell beds, and the internal winnowed surfaces within complex shell beds, represent the great majority of time, while the shales between record geological instants of storm mud deposition (see discussion in Parsons et al., 1986; Miller, in press). The basal portions of shell beds typically consist of corroded, abraded, and highly fragmented shell material, which may include a resistant residue of durable skeletal elements like crinoid ossicles. This contrasts with the excellent preservation observed on shell bed tops. The articulated, multi-element skeletons of crinoids and trilobites, and life position brachiopods and corals, are persuasive evidence of rapid burial. The small-scale stratigraphic discontinuities represented by the winnowed and eroded surfaces associated with these shell beds are not different in principle from unconformities used as isochrons in sequence stratigraphy.

The ability to trace very thin marker beds over hundreds of kilometers is not unique to the northern Appalachian Basin. The time-parallel nature of such beds has also been previously demonstrated by other workers for other stratigraphic settings. For example, Hattin (1985) has successfully correlated closely spaced, thin chalky limestone beds within calcareous shales of the Upper Cretaceous over large areas of the western interior of the United States. A wide range of event bed types are potentially available as the basis for very high-resolution correlation, and Kauffman (1988) has synthesized these into a system of chronostratigraphy called "High-Resolution Event Stratigraphy" (HIRES).

DESCRIPTION AND INTERPRETATION OF CYCLIC PATTERNS

Proximality Spectrum of Storm-Event Beds

The vertical trends in shell bed taphonomy exhibited by the Darien Center Submember, and by other stratigraphic intervals within the Hamilton Group, can be used to reconstruct a bathymetric gradient of storm-generated event beds. As seen from the descriptions above, shell beds typically have a basal winnowed, or non-depositional, shell lag colonized by an *in situ* well-preserved epifaunal assemblage and subsequently buried by a rapidly deposited layer of poorly fossiliferous mud. The Darien Center Submember displays a nearly symmetric cyclic pattern in the taphonomy and internal structure of these storm-event beds. Within the central portion of the submember, between the Lakeview and Fargo Beds, amalgamated or multi-event shell beds containing several superimposed fossil layers are typical. These beds were probably deposited well within storm wave-base. As the degree of basal scour and erosion decreases away from this central portion of the interval, shell beds lose their amalgamated character and become thinner until reduced to shell pavements only a single shell layer thick. The shales with shell pavements lacking any evidence of basal scour are presumed to have been deposited below the effective base of even the most severe storms. Mud burial layers overlying the shell beds are up to 10 centimeters thick near the center of this cyclic sequence, and decrease to one centimeter or less over the shelly pavements near the boundaries of the cycle.

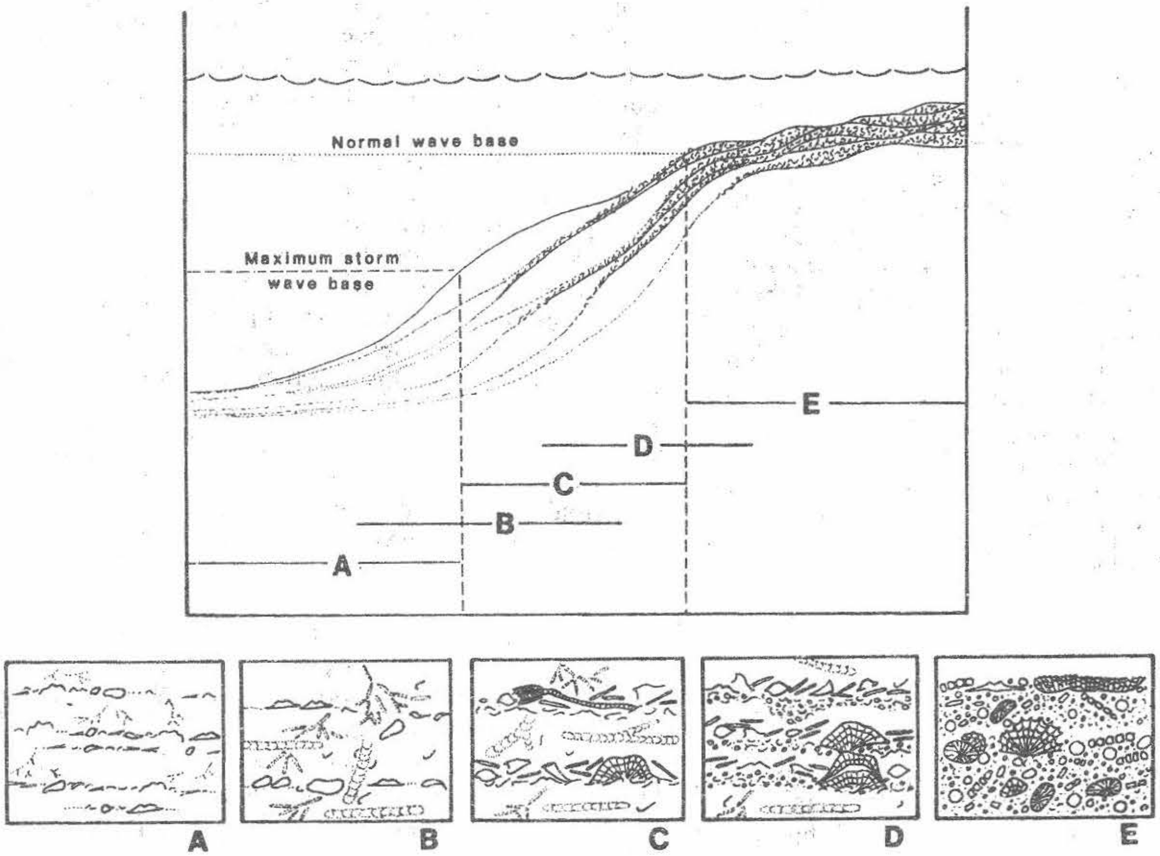

Figure 5. Diagram of storm depositional model showing successive event deposits produced by storms of varying intensity. Lettered bars show expected depth ranges of different shell bed types: A) non-depositional surfaces smothered by thin distal mud layers, B) colonized soft-bottom surfaces buried by upslope winnowed muds, C) colonized winnowed pavements buried by thick layers of redeposited muds, D) rewinnowed and amalgamated shell beds smothered by thick mud layers, and E) winnowed crinoidal grainstones with a few subtle internal burial horizons. Reprinted from Miller and others (1988) with permission of S.E.P.M.

A very simplified model of storm deposition proposed by Miller and others (1988) can explain these observed trends. During any given storm, winnowing would occur above storm wave-base, with mud redeposited in a basinward-thinning wedge below storm wave-base. The absolute depth at which winnowing and mud deposition occur would vary with storm intensity. Averaged over many storms, mud layers would tend to be thickest somewhat below the reach of the "average" storm and taper into deeper water. Conversely, the frequency and intensity of storm winnowing would tend to increase into shallower water environments with the increasing occurrence of shell bed amalgamation and multiple reworking. No mud layers would be expected above fairweather wave-base where wave agitation would be an essentially continuous process. A proximality spectrum of shell beds is therefore generated which can be used to estimate depth relative to fairweather and storm wave-base (see Fig. 5). Though similar to other models of storm-bed sedimentation (Aigner and Reineck, 1982; Aigner, 1985; Driese, 1988), this model focuses on the more distal spectrum of storm-related deposits common within fine-grained offshore marine sediments. The more distal range of events beds preserved in the Darien Center Submember is also ideal for the excellent *in situ* preservation of a highly diverse, benthic fauna.

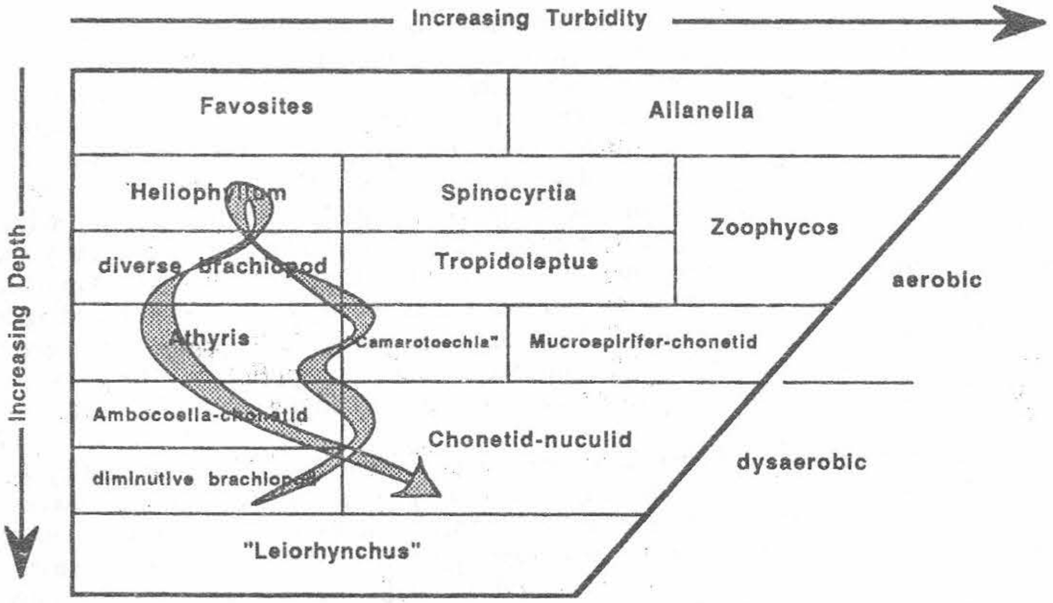

Figure 6. Paleoecologic model for Hamilton benthic assemblages showing relationships to inferred gradients of depth and turbidity and/or sedimentation rate (modified from Brett *et al.*, 1986). Arrowed path shows vertical sequence of assemblages for Elevenmile Creek locality.

Depth Gradients of Fossil Assemblages

The symmetrical cyclic pattern in storm bed taphonomy within the Darien Center Submember is matched quite closely by the vertical sequence of associated fossil assemblages. These assemblages are interpreted as representing bathymetric facies belts which migrated laterally in response to a regressive-transgressive cycle. The relative ordering of these assemblages is part of the consistent pattern of recurrent and laterally intergrading assemblages of the Hamilton Group which have been recognized by many workers, and related to gradients of depth and turbidity (see references in Brett *et al.*, 1986b). The depth and turbidity limits for the recurrent faunal assemblages of the Hamilton Group are summarized in Fig. 6. Recent work on the density and diversity of microborings within Hamilton assemblages (Vogel *et al.*, 1987) has supported these proposed depth and turbidity relationships. Further, the presence of algal microborings in all facies indicates a range of depths entirely within the photic zone.

The close parallel of taphonomic and faunal trends raises interesting questions regarding the extent and nature of the interaction between the dynamics of the physical environment and the benthic fauna. The depth ranges of benthic taxa may have been controlled to a large degree by the frequency and intensity of storm activity (Miller *et al.*, 1988). As different regimes of physical disturbance migrated up and down slope with changing sea level, they would have been tracked by their resident disturbance-adapted benthic faunas, resulting in the observed vertical sequence of fossil assemblages.

Reconstruction of Depth and Eustatic Sea-Level Curves

The depth relationships of the benthic assemblages of the Hamilton can be used to reconstruct depth curves. Since the composition of the benthic fauna appears to have been highly sensitive to depth, detailed centimeter by centimeter sampling of stratigraphic intervals can provide the basis for depth curves of very fine temporal, and bathymetric, resolution. The diagram of Fig. 6 can be used to visually display the changing depths (and turbidities) recorded by the vertical sequence of benthic assemblages at a given locality. A "path" can be drawn on this diagram tracing out the sequence of assemblages encountered from the base of the Darien Center Submember to its top. An example of one such path, shown on Fig. 6, clearly shows the regressive-transgressive nature of the interval. Note that the path is a closed loop indicating a return to origin conditions, and the completion of a sedimentary cycle. From this diagram, it also is apparent that the regressive half of the cycle was deposited under somewhat more turbid conditions than the transgressive half. This latter conclusion is supported by the more condensed character and higher fossil density of the upper portion of the cycle.

When the presence/absence faunal data is examined in more detail, an additional cyclic pattern can be recognized which is superimposed on the general regressive/transgressive cycle (Miller, in press). This subcyclicity is reflected in sharp changes in faunal diversity closely associated with the widely traceable key beds (see Figs. 11, 12, 13 in road log). Sudden diversity increases are associated with the Girdle Road and Lakeview Beds, and diversity decreases are associated with the Murder Creek and Bidwell Beds. Highest faunal diversities are recorded within amalgamated shell beds between the Darien Coral Bed and the Fargo Bed. These diversity fluctuations, together with the symmetrical pattern of depth-controlled faunal assemblages, have been used to reconstruct a depth curve for the Darien Center Submember (Fig. 7). This depth curve is used to infer an eustatic sea-level curve with two superimposed cycles of different periodicites. The apparent association of key beds with the subcycle boundaries is significant in providing another line of argument for the isochroneity of these widely traceable beds.

At least five subcycles are recognized within the thin Darien Center interval, each bounded by key beds. Though not shown on Fig. 7, a sixth subcycle is probably recorded by the interval between the Mt. Vernon Bed and the undulatory Stolle Road Bed. The prominent fossil horizons occurring at the boundaries of these cycles appear to be condensed beds and probably record periods of reduced sediment accumulation associated with increased sediment bypass and/or reduced sediment supply. The apparent asymmetry of the subcycles is very interesting and significant. Those subcycles within the regressive phase of the larger cycle have condensed regressive portions, and those within the transgressive phase have condensed transgressive portions. The superimposition of a hierarchy of eustatic cycles would be expected to generate just such accentuated regressions and transgressions. As a result, deepening upward subcycles are produced during regression, and shallowing upward subcycles are produced during transgression.

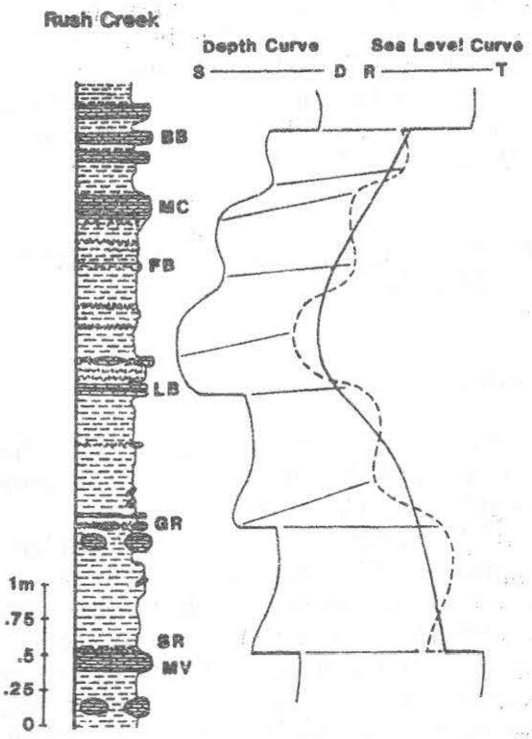

Figure 7. Stratigraphic column from Rush Creek with interpreted depth and sea-level curves for Darien Center Submember based on taphonomic and faunal patterns. Solid sea-level curve represents 5th order regressive-transgressive cycle and dashed line indicates superimposed 6th order subcycles. The Stolle Road Bed (SR), which immediately overlies the Mt. Vernon Bed (MV) at the base of the interval, represents an additional complete subcycle not shown on the curve (see Miller,1988, ch.3). The Girdle Road Bed (GR) is a subtle, but widespread, key bed within the regressive half-cycle.

The subcycles recognized within the calcareous shales and thin limestones of western New York have been correlated across the basin axis of the northern Appalachian Basin into the siltstones and hummocky cross-stratified sandstones of the eastern clastic ramp (Miller, 1988). The regressive subcycles are progressively lost on the eastern margin of the basin axis, and the transgressive subcycles become prominent coarsening-upward clastic cycles (Brett *et al.* 1986b). Specifically, the subcycles bounded by the Lakeview and Fargo Beds and by the Fargo and Murder Creek Beds can each be correlated with 5 to 7 meter-thick coarsening-upward cycles to the east. Likewise, the interval between the Murder Creek and Bidwell Beds appears to correlate with a thinner 1 meter coarsening-upward cycle. The traceability of these cycles across significant thickness and facies changes argues for a basinwide eustatic causal mechanism.

The absolute duration of the cycles recorded by faunal and taphonomic data are very difficult to estimate (Miller, in press). This is in part due to the absence of high-resolution biostratigraphic markers and datable horizons such as bentonites. The time scale for deposition of the entire Darien Center Submember is much smaller than that resolvable with traditional biostratigraphy, with the complete regressive-transgressive cycle representing only a fraction of single conodont and ammonoid zones. The most severe difficulty, however, is that surfaces rather than sediment record the vast majority of geologic time (Ager, 1981; Dott, 1983). If the marker beds were found to represent more time than the cyclic intervals which they bound, the durations of those cycles would be seriously overestimated. Nonetheless, crude order of magnitude approximations are possible by subdividing the Hamilton Group using a recognized hierarchy of sedimentary cycles. The Hamilton Group as a whole includes the uppermost Eifelian and much of the Givetian

(Klapper, 1981), a duration of about 6 million years. It has been divided into three transgressive-regressive cycles by Johnson and others (1985), which they believe are correlative over Euramerica. The Darien Center cycle, in turn is one of 14 or 15 yet smaller cycles within the Hamilton Group (Brett and Baird, 1986b). Simple division yields time estimates for these cycles of 300 to 400 thousand years, a value roughly comparable to midcontinent cyclothems, or to 5th order T-R cycles as defined by Busch and Rollins (1984) and Busch and West (1987). The six subcycles likely present within the Darien Center Submember would therefore represent perhaps 50 thousand years, a period at the short end of the time range estimated for punctuated aggradational cycles (Goodwin and Anderson, 1985) and 6th order T-R cycles (Busch and West, 1987). It must be emphasized that these time estimates are only a general first approximation, and merely provide an upper limit to the duration of these cyclic patterns (see Algeo and Wilkinson, 1988).

FORMATION OF AN UNDULATORY DISCONTINUITY SURFACE DURING REGRESSIVE PHASE OF CYCLE

Description of Undulatory Surface

The undulatory nature of the Stolle Road Bed has already been briefly discussed. The irregular nature of the concretionary horizon associated with this shell bed was first reported by McCollum (1981) for exposures along the banks of Buffalo Creek. However, this concretionary horizon was misindentified as the Mt. Vernon Bed, and interpreted as a late diagenetic artifact. As a result, McCollum abandoned the Mt. Vernon Bed as the basal boundary of the Wanakah Member in preference to the first appearance of the tabulate coral *Pleurodictyum*, the definition utilized by Cooper (1930) for localities to the east of the Genesee Valley. More recent detailed study, however, has recognized that a traceable shelly and pyritic horizon immediately overlies the undulating concretion layer, and that the Mt. Vernon Bed itself remains nearly horizontal and marks the base of lenticular bodies of nearly barren blue-gray shale. The Mt. Vernon Bed can be traced as a persistent shell bed even though the diagenetic concretionary limestone with which it is usually associated becomes discontinuous or is completely lost below the barren shale lenses. Its diagnostic fauna makes it an easily recognized marker bed, and it therefore should be retained as the basal boundary of the Wanakah Shale Member according to Cooper's (1930) original definition.

The repeated splaying and coalescence of the Mt. Vernon and Stolle Road Beds can be seen in the sketch of the stream bank exposure shown in Fig. 8. The appearance is one of a series of irregularly spaced swells on an otherwise flat surface. The swells differ substantially in amplitude, varying from a few tens of centimeters to nearly a meter and a half in height, and similarly range from 10 to over 60 meters in width. Also recognizable from Fig. 8 is the slight but consistent asymmetry of the swells, with the western margins noticeably steeper than the eastern margins. At Pond Brook, a nearby tributary to Buffalo Creek, some indication of the orientation of these structures can be obtained. At that locality, a N12,E trend was measured for a single swell exposed on both banks of the stream. This NNE-SSW orientation is significant, bcause it represents a nearly onshore-offshore direction based on the reconstructed basin paleogeography (see Fig. 1).

The detailed relationships between concretionary horizons and bedding surfaces for two swells are shown in Fig. 9. This diagram illustrates the important characteristics of the undulatory horizon and of the entire regressive half of the Darien Center cycle. Three distinct

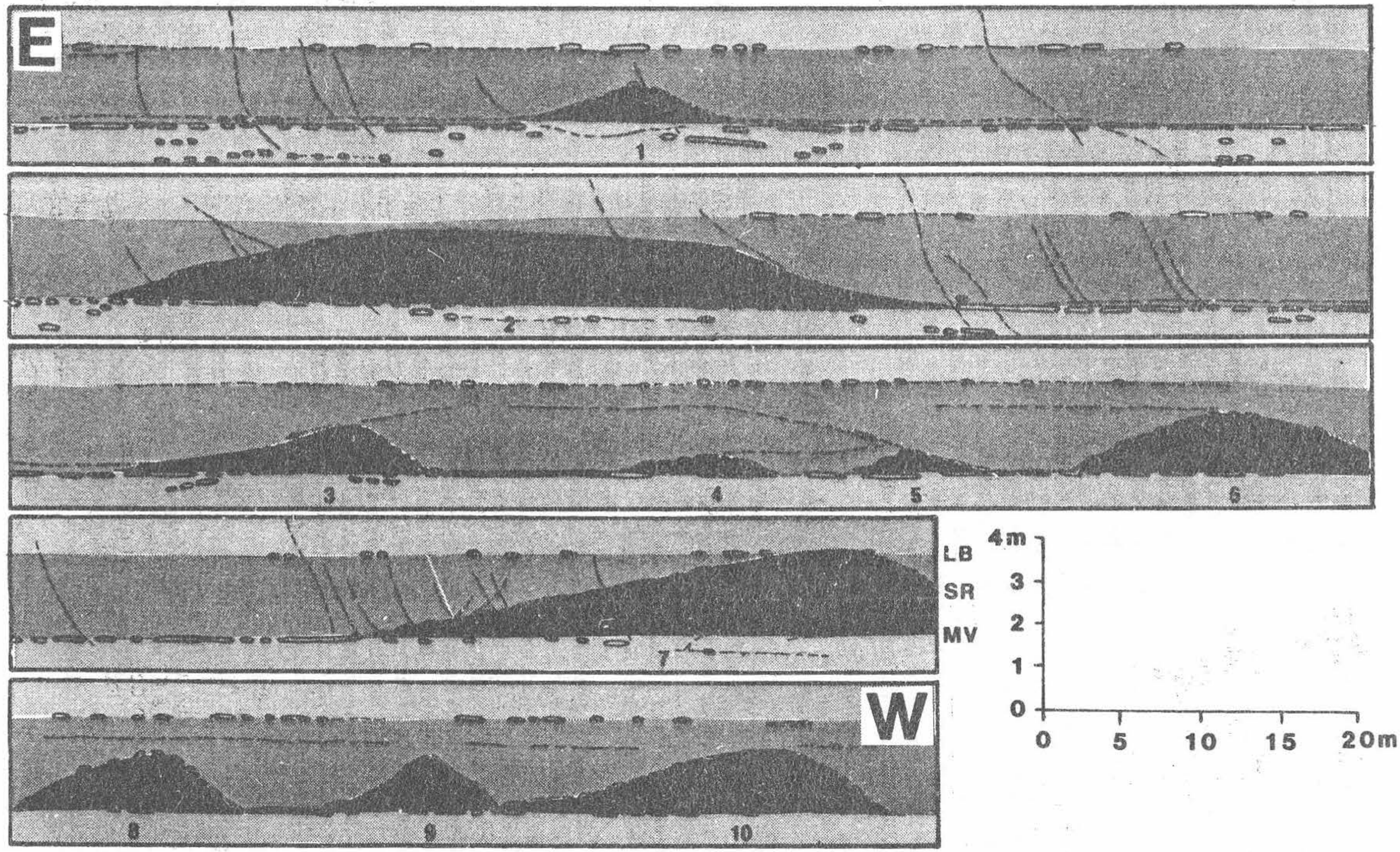

Figure 8. Sketch based on photographs of nearly 500-meter-long section of Buffalo Creek cut bank showing the outcrop appearance of the swells (highlighted with dark shading) and their variable spacing and amplitude. Individual swells are numbered. Vertical scale has three-fold exaggeration, and the scale shown is approximate. Labelled beds are: MV) Mt. Vernon Bed, SR) Stolle Road Bed, and LB) Lakeview Bed.

intervals can be distinguished: 1) the nearly barren shales below the Stolle Road Bed, 2) the fossil-poor shales filling the broad "channels" between swells, and 3) the closely-spaced fossil horizons overlying the Girdle Road Bed.

Below the Stolle Road Bed, the lenses of hard blue-gray shale tend to stand out somewhat on the stream bank exposures. As mentioned earlier, the ellipsoidal carbonate concretions which conveniently outline the swells in outcrop tend to occur several centimeters below the undulating shelly and pyritic layer of the Stolle Road Bed. Within larger swells, ellipsoidal concretions, as well as thin discontinuous carbonate layers, appear to define other internal undulatory horizons which may either be concordant or discordant with the contours of the swells. These indistinctly defined horizons are only infrequently associated with discernable fossil layers. Between the Stolle Road and Girdle Road Beds are poorly fossiliferous gray shales with abundant *Zoophycus* spreiten. These shales pinch out against the swells, and rare laterally restricted fossil pavements and pyritic horizons within this interval can be seen to truncate against the sides of the swells and may slope away from them (see Fig. 9B). The Girdle Road Bed, which contains a moderately diverse fauna, is amalgamated to the tops of the larger swells, and may even truncate them somewhat (see Fig. 9A). The fossiliferous gray calcareous shales above the Girdle Road Bed contain closely-spaced shell beds that appear relatively unaffected by the underlying irregularities.

Depositional Dynamics

Because of the fine-grained nature of the sediments within which the undulatory Stolle Road Bed surface was formed, it is highly unlikely that the swells represent bedforms built by bedload transport. However, two sedimentary features reported from modern marine environments provide possible analogs: 1) longitudinal ripples, and 2) sedimentary furrows. The formation of both of these structures is believed to be associated with secondary helical flow cells within bottom-flowing currents.

Small silty-clay longitudinal ripples have been described from the ocean floor at depths of almost 5000 meters. These 2-10 meter long bedforms are symmetrical in cross-section, up to 15 cm high and 75 cm wide and are spaced about 1-2 meters apart over an essentially flat surface (Flood, 1981a). Though these ripples are smaller than the Wanakah mud swells by more than an order of magnitude, their morphology is surprisingly similar. Also, a field of discontinuous ripples developed on a planar surface would yield a cross-sectional appearance very like that of the swells, with apparent uneven spacing and variable amplitudes. The depositional dynamics of these longitudinal ripples therefore needs to be considered. McCave and others (1984) argue that the ripples were formed by rapid deposition from a concentrated suspension under waning current conditions. They and Flood (1981a) suggest that short-lived, high velocity bottom currents eroded 1-2 cm of fine sediment over the ripple field, and then redeposited it in longitudinal ripples in response to secondary helical flow.

Large linear erosive features, probably similar in origin to gutter casts, have been described from both shallow-water (Flood, 1981b) and abyssal environments (Hollister *et al.*, 1974; Flood and Hollister, 1980). These sedimentary furrows appear to provide the best actualistic model for the undulatory surface. Furrows are characterized by steep sides and flat floors, and range in size from gutter-like "minifurrows" (Flood, 1981b) to large furrows up to 150 meters wide and 20 meters deep (Hollister *et al.*, 1974). Of particular interest is the presence of shell lags on the furrow floors. The shallow-water estuarine furrows described by Flood (1981b) have layers of articulated cockle shells up to 7 cm thick. These are strikingly similar to the

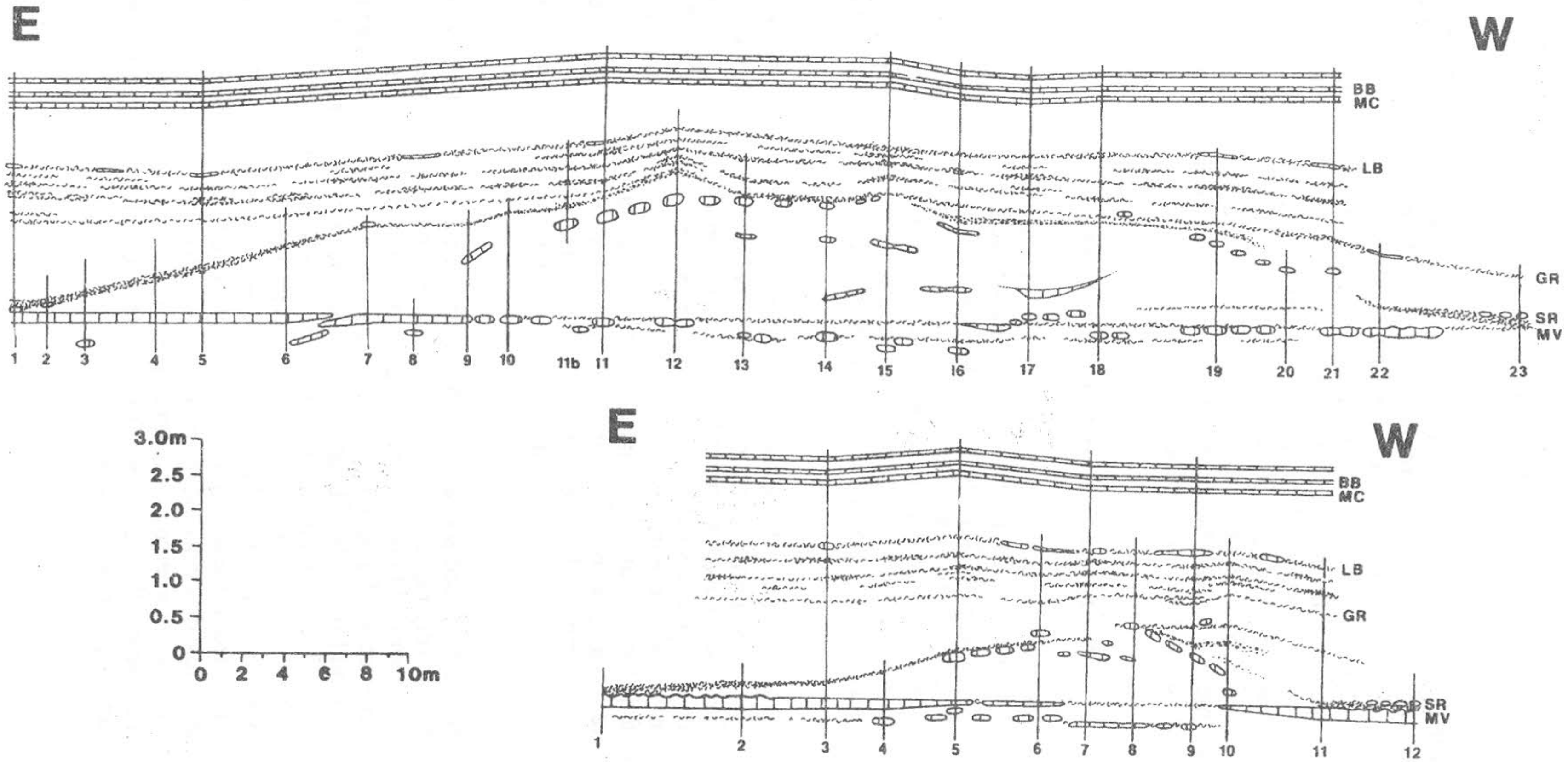

Figure 9. Detailed drawings of two swells based on measurements from closely spaced vertical transects: (A) corresponds to swell 2 of Figure 4, and (B) corresponds to swell 3. Numbers mark measured vertical transects. Important marker beds are indicated by letters as follows: MV) Mt. Vernon Bed; SR) Stolle Road Bed; GR) Girdle Road Bed; LB) Lakeview Bed; MC) Murder Creek Bed; and BB) Bidwell Bed, which marks top of Darien Center Submember. Note the three distinct stratigraphic intervals discussed in text: 1) between the undulating Stolle Road Bed and the Mt. Vernon Bed, 2) between the Stolle Road and Girdle Road Beds, and 3) between the Girdle Road and Lakeview Beds. Although shown blank, the interval between the Lakeview and Murder Creek Beds is also highly fossiliferous and characterized by closely spaced shell beds.

Ambocoelia-rich fossil layers of the Stolle Road Bed found on the "channel floors" between the swells.

As in the case of longitudinal ripples, the origin of furrows is believed to be associated with secondary helical flow cells. Flood (1981b) proposes that "minifurrows" are initiated by the scouring action of rows of shells aligned by converging helical cells. According to this interpretation, these minifurrows are subsequently deepened and widened during "erosional events" by the abrasive action of the coarse shell material concentrated on the furrow floors. Study of deep-sea furrows by Flood and Hollister (1980) has shown that once formed, furrows may persist for periods exceeding 10,000 years. Furthermore, they also appear to be fairly dynamic with active deposition on furrow walls. This observation is significant in indicating that furrows may be formed by combinations of erosive and depositional processes under at least moderately aggradational conditions.

Proposed Depositional History

From the preceding discussions of the inferred sea level fluctuations within the Darien Center Submember, and of the physical processes which may have contributed to the formation of the undulatory surface, a plausible depositional history can be constructed. The principle phases of this history are 1) the formation of the mud swells on a previously planar surface, 2) the filling of "channels" between the swells in response to sea-level rise, 3) the development of a shelly lag during subsequent sea-level fall, and 4) the accumulation of winnowed/non-depositional shell beds and rapidly deposited mud layers on a nearly planar storm-influenced sea floor.

Based on the models of longitudinal ripples and sedimentary furrows, two scenarios seem possible for producing the unusual irregular geometry of the nearly barren mudrocks overlying the Mt. Vernon Bed. The first involves a primarily erosive mechanism following initial rapid mud deposition. During accentuated shallowing resulting from the regression of the first subcycle, episodic storm-driven currents began resuspending and entraining sediment. Erosion was concentrated along linear current-parallel paths by helical secondary flow. Beginning as gutter-like scours, furrows deepened and widened with time, at least in part due to the abrasive action of shell material concentrated on their floors. Bottom current flow became more and more channelized, and the furrows widened until the present geometry was attained.

According to the second proposed scenario, the formation of the mud swells proceeded synchronously with the relatively rapid aggradation of sediment over the Mt. Vernon Bed. In this case, episodic storm-generated bottom currents, laden with suspended sediment winnowed from nearer shore by wave action, deposited sediment in parallel longitudinal features in response to secondary helical flow cells. Elongate mud ridges were built up progressively as mud continued to be supplied to the shelf area below storm wave-base. As in the first scenario, the developing bottom topography increasingly controlled subsequent current flow patterns. Sediment bypass and winnowing in the areas between ridges, especially during subsequent shallowing, resulted in the accumulation of a styliolinid and *Ambocoelia*-rich shell hash layer. Both scenarios just described have end results which could be quite similar. The preesent data probably points to some combination of these processes. The irregular winnowed surfaces within the swells would seem to indicate a complex dynamic history involving both erosive and depositional processes.

Events following the formation of a field of elongate onshore-offshore-oriented mud ridges or furrows can be more confidently reconstructed. With the change to deepening conditions associated with a second transgressive/regressive subcycle, the offshore-directed bottom currents no longer affected the area, and sediment began accumulating between the ridges. The very low fossil abundances and near absence of shelly horizons within the shales filling the inter-swell "channels" point to a relatively rapid filling of the bottom topography. By the conclusion of this depositional phase, the sea floor was again nearly planar.

Another accelerated shallowing, due to the regressive kick of the second subcycle, resulted in widespread sediment bypass and the formation of the nearly planar Girdle Road Bed. Subsequent slight deepening of the third subcycle was accompanied by renewed deposition under conditions of episodic storm influence near the limit of storm wave-base. Nearly uniform, rapidly deposited, storm mud layers alternating with simple shell beds and shell pavements now accumulated over a flat, very gently sloping bottom. The regressive kick of the third transgressive/regressive subcycle resulted in the generation of a multiply rewinnowed complex shell bed (ie. the Lakeview Bed) which is overlain by the coral-rich horizon marking the time of maximum shallowing of the larger Darien Center Submember cycle. After a period of low sea level stand, a series of three transgressive pulses, punctuated by relatively rapid regressions or stillstands, returned conditions to those that existed during the formation of the Mt. Vernon Bed. These transgressive pulses reflect the three subsequent subcycles, and were associated with relatively low sedimentation rates resulting in a more condensed and fossil-rich interval.

ACKNOWLEDGMENTS

This paper is based on work conducted under the direction of C. E. Brett with the support of a grant from the National Science Foundation (no. EAR-8313103). I express my appreciation to R. R. West and A. W. Archer whose critical reviews helped clarify my thoughts and expression. My wife R. D. Miller provided assistance in the field, and with word processing.

REFERENCES CITED

AGER, D.V., 1981, The Nature of the Stratigraphical Record, 2nd edition, John Wiley & Sons, New York, 122 p.

AIGNER, T., 1984, Dynamic stratigraphy of epicontinental carbonates, Upper Muschelkalk (M. Triassic), South-German Basin: Neues Jb. Geol. Paläont. Abh., v.169, p.127-159.

_____, 1985, Storm depositional systems: dynamic stratigraphy in modern and ancient shallow-marine sequences: Lecture Notes in Earth Sciences 3, Springer-Verlag, Berlin, 174p.

_____ and Reineck,H.-E., 1982, Proximality trends in modern storm sands from the Helgoland Bight (North Sea) and their implications for basin analysis: Senckenbergiana Maritima, v.14, p.183-215.

ALGEO, T.J. and WILKINSON, B.H., 1988, Periodicity of mesoscale Phanerozoic sedimentary cycles and the role of Milankovitch orbital modulation: Jour. Geol., v.96, p.313-322.

BAIRD, G.C., 1981, Submarine erosion on a gentle paleoslope: a study of two discontinuities in the New York Devonian: Lethaia, v.14, p.105-122.

BERNER, R.A., 1968. Calcium carbonate concretions formed by the decomposition of organic matter: Science, v.159, p.195-197.

BRETT, C.E. and BAIRD G.C., 1985, Carbonate-shale cycles in the Middle Devonian of New York: An evaluation of models for the origin of limestones in terrigenous shelf sequences: Geology, v.13, p.324-327.

_____ and _____, 1986a, Comparative taphonomy: a key to paleoenvironmental interpretation based on fossil preservation: Palaios, v.1, p.207-227.

_____ and _____, 1986b, Symmetrical and upward shallowing cycles in the Middle Devonian of New York State and their implications for the punctuated aggradational cycle hypothesis: Paleooceanography, v.1, p.431-445.

_____ and COTTRELL, J.F., 1982, Substrate specificity in the Devonian tabulate coral *Pleurodictyum* : Lethaia, v.15, p.247-262.

_____, SPEYER, S.E. and BAIRD, G.C., 1986a, Storm-generated sedimentary units: tempestite proximality and event stratification in the Middle Devonian Hamilton Group of New York, *in* Brett, C.E., ed., Dynamic Stratigraphy and Depositional Environments of the Hamilton Group (Middle Devonian) in New York State, Part 1: New York State Mus. Bull., v. 457, p.129-156.

_____, BAIRD, G.C. and MILLER, K.B., 1986b, Sedimentary cycles and lateral facies gradients across a Middle Devonian shelf-to-basin ramp, Ludlowville Formation, Cayuga Basin, *in* Cisne, J.L., ed., New York State Geol. Assoc. 58th Annual Mtg. Field Trip Guidebook, Cornell University, p.81-127.

_____, MILLER, K. B. and BAIRD, G. C., in press, A temporal hierarchy of paleoecologic processes within a Middle Devonian epeiric sea, *in* Miller, W., III, ed., Paleocommunity Temporal Dynamics: The Long-Term Development of Multispecies Assemblies: Paleontological Society Special Publication.

BUSCH, R.M. and ROLLINS, H.B., 1984, Correlation of Carboniferous strata using a hierarchy of transgressive-regressive units: Geology, v.12, p.471-474.

_____ and WEST, R.R., 1987, Hierarchical genetic stratigraphy: A framework for paleoceanography: Paleoceanography, v.2, p.141-164.

COOPER, G.A., 1930, Stratigraphy of the Hamilton Group of New York: Amer. Jour. Sci., v.19, p.116-134, 214-236.

COTTER, E., 1983, Silurian depositional history, *in* Nickelsen, R.P. and Cotter, E., eds., Silurian Depositional History and Alleghanian Deformation in the Pennsylvania Valley and Ridge: 48th Annual Field Conference of Pennsylvania Geologists, Lewisburg, p.3-28.

DENNISON, J.M., 1985, Catskill delta shallow marine strata, *in* Woodrow, D.L. and Sevon, W.D., eds., The Catskill Delta: Geol. Soc. Amer. Spec. Publ. 201, p.91-106.

DOTT, R.H., 1983, 1982 S.E.P.M. Presidential address: Episodic sedimentation -- How normal is average? How rare is rare? Does it matter? : Jour. Sed. Petrol., v.53, p.5-23.

DRIESE, S.G., 1988, Depositional history and facies architecture of a Silurian foreland basin, eastern Tennessee, *in* Driese, S.G. and Walker, D., eds., Depositional History of Paleozoic Sequences, Southern Appalachians: Univ. of Tenn., Dept. of Geol. Sci., Studies in Geology, no.19, p.62-96.

FLOOD, R. D., 1981a, Longitudinal triangular ripples in the Blake-Bahama Basin: Marine Geology, v.39, p.M13-M20.

_____, 1981b, Distribution, morphology, and origin of sedimentary furrows in cohesive sediments, Southampton Water: Sedimentology, v.28, p.511-529.

_____ and HOLLISTER, C. D., 1980, Submersible studies of deep-sea furrows and traverse ripples in cohesive sediments: Marine Geology, v.36, p.M1-M9.

GOODWIN, P.W. and ANDERSON, E.J., 1985, Punctuated aggradational cycles: general hypothesis of episodic stratigraphic accumulation: Jour. Geol. v.93, p.515-533.

_____, _____, GOODMAN, W.M. and SAROKA, L.J., 1986, Punctuated aggradational cycles: implications for stratigraphic analysis: Paleoceanography, v.1, p.417-429.

GRABAU, A.W., 1899, The palaeontology of Eighteen Mile Creek and the lake shore sections of Erie County, New York: Buffalo Soc. Nat. Sci. Bull., v.6, nos. 2,3,4.

HATTIN, D.E., 1985, Distribution and significance of widespread, time-parallel pelagic limestone beds in the Greenhorn Limestone (Upper Cretaceous) of the central Great Plains and southern Rocky Mountains, in Pratt, L.M., Kauffman, E.G., and Zelt, F.B., eds., Fine-grained Deposits and Biofacies of the Cretaceous Western Interior Seaway: Evidence of Cyclic Sedimentary Processes: Soc. Econ. Paleon. Mineral., 2nd Annual Midyear Mtg., Field Trip Guidebook No. 4, Golden, Colo., p.28-37.

HOLLISTER, C. D., FLOOD, R. D., JOHNSON, D. A., LONSDALE P. and SOUTHARD, J. B., 1974, Abyssal furrows and hyperbolic echo traces on the Bahama Outer Ridge: Geology, v.2, p.395-400.

JOHNSON, J.G., KLAPPER, G. and SANDBERG, C.A., 1985, Devonian eustatic fluctuations in Euramerica: Geol. Soc. Amer. Bull., v.96, p.567-587.

KAUFFMAN, E.G., 1988, Concepts and methods of high-resolution event stratigraphy: Ann. Rev. Earth Planet. Sci., v.16, p.605-654.

KLAPPER, G., 1981, Review of New York Devonian conodont biostratigraphy, *in* Oliver, W.A. and Klapper, G., eds., Devonian Biostratigraphy of New York, Part 1: International Union of Geol. Sci. Subcomm. on Devonian Stratigraphy, pp.57-66.

KLOC, G.J., 1983, Stratigraphic distribution of ammonoids from the Middle Devonian Ludlowville Formation in New York [unpub. MA thesis]: State Univ. at Buffalo, 73p.

McCAVE, I.N., HOLLISTER, C.D., DeMASTER, D.J., NITTROUER, C.A., SILVA, A.J. and YINGST, J.Y., 1984, Analysis of a longitudinal ripple from the Nova Scotian continental rise: Marine Geology, v.58, p.275-286.

McCOLLUM, L.B., 1981, Distribution of marine faunal assemblages in a Middle Devonian stratified basin, lower Ludlowville Formation, New York [unpub. doctoral dissertation]: State University of New York at Binghamton, 143 pp.

MILLER, K.B., 1986, Depositional environments and sequences, "*Pleurodictyum* Zone", Ludlowville Formation of western New York, *in* Brett, C.E., ed., Dynamic Stratigraphy and Depositional Environments of the Hamilton Group (Middle Devonian) in New York State, Part 1: New York State Mus. Bull. v.457, p.57-77.

_____, 1988, A temporal hierarchy of paleoecologic and depositional processes across a Middle Devonian epeiric sea [doctoral dissertation]: Univ. of Rochester, 249p.

_____, in press, High-resolution correlation within a storm-dominated muddy epeiric sea: taphofacies of the Middle Devonian Wanakah Member, *in* Landing, E. and Brett, C.E., Dynamic Stratigraphy and Depositional Environments of the Hamilton Group (Middle Devonian) in New York State, Part 2: New York State Mus. Bull.

_____, PARSONS, K.M. and BRETT, C.E., 1988, The paleoecologic significance of storm-generated disturbance within a Middle Devonian muddy epeiric sea: Palaios v.3, p.35-52.

NORRIS, R.D., 1986, Taphonomic gradients in shelf fossil assemblages: Pliocene Purisma Formation, California: Palaios, v.1, p.256-270.

PARSONS, K.M., BRETT, C.E. and MILLER, K.B., 1988, Taphonomy and depositional dynamics of Devonian shell-rich mudstones: Palaeogeog. Palaeoclim. Palaeoecol., v.63, p.109-139.

READ, J.F., 1980, Carbonate ramp-to-basin transitions and foreland basin evolution, Middle Ordovician, Virginia Appalachians: Amer. Assoc. of Petrol. Geol. Bull., v.64, p.1575-1612.

SAVARESE, M., GRAY, L.M. and BRETT, C.E., 1986, Faunal and lithologic cyclicity in the Centerfield Member (Middle Devonian: Hamilton Group) of western New York: a reinterpretation of depositional history, *in* Brett, C.E., ed., Dynamic Stratigraphy and Depositional Environments of the Hamilton Group (Middle Devonian) in New York State, Part 1: New York State Mus. Bull. v.457, p.32-56.

VOGEL, K., GOLUBIC, S. and BRETT, C.E., 1987, Endolith associations and their relation to facies distribution in the Middle Devonian of New York State: Lethaia, v.20, p.263-290.

WALKER, K.R., SHAMMUGAN, G. and RUPPEL, S.C., 1983, A model for carbonate to terrigenous clastic sequences: Geol. Soc. Amer. Bull., v.94, p.700-712.

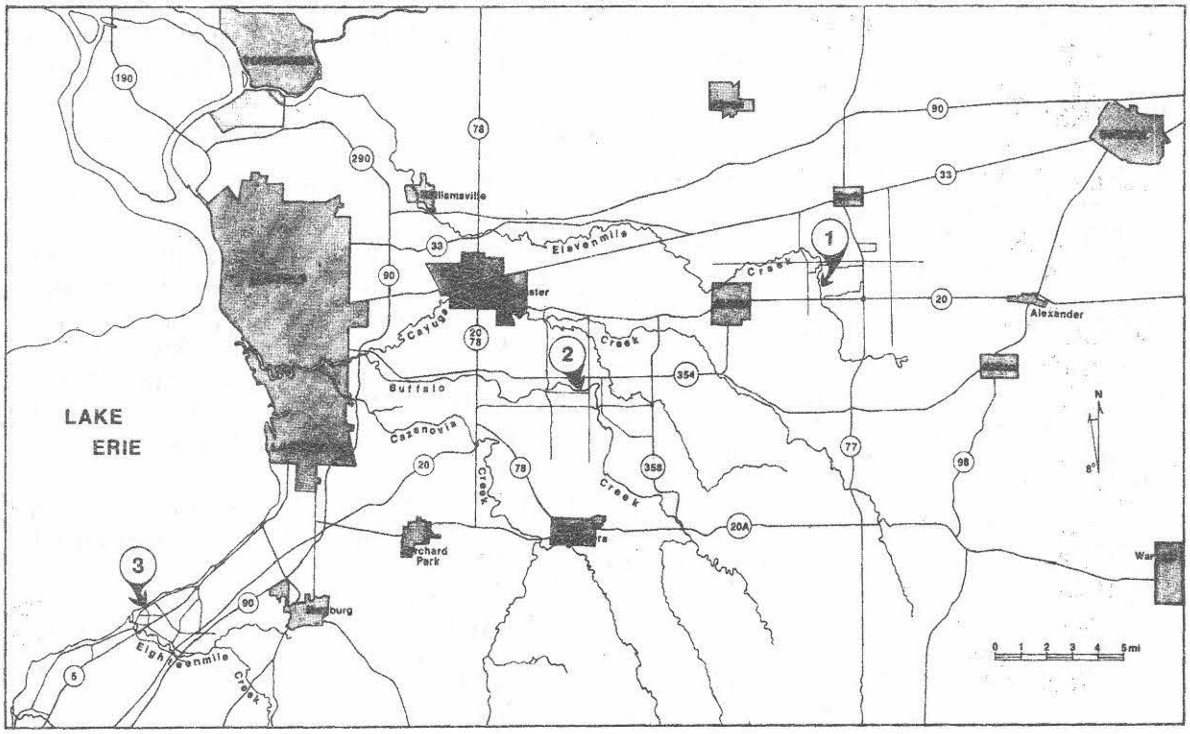

Figure 10. Locality map for the three field trip stops.

ROAD LOG FOR THE PALEOECOLOGY AND SEDIMENTOLOGY OF THE DARIEN CENTER SUBMEMBER

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Road log begins at exit 53 on the New York State Thruway (I 90) around Buffalo. Turn east on Clinton Street (Rt. 354).
2.0	2.0	Cross Union Road (Rt. 277) at Gardenville. Continue on Clinton Street paralleling Buffalo Creek.

4.9	2.9	Cross Transit Road (Rts. 20/78)
12.0	7.1	Cross Two Rod Road (Rt. 358).
14.5	2.5	Cross Cayuga Creek.
14.7	0.2	Bear left (north) onto Exchange Street (Rt. 239) toward the town of Alden.
17.7	3.0	At Alden turn right (east) onto Broadway (Rt. 20).
20.9	3.2	Turn left (north) on Harlow Road. Darien Lakes State Park will be on your right after the turn.
21.4	0.5	Turn right into Park entrance. After passing the gate house drive to left around small recreational lake and then bear right and continue to end of camping area and park vehicles. A nature trail leads to Elevenmile Creek just down the bank.

STOP 1 - ELEVENMILE CREEK AT DARIEN LAKES STATE PARK

The streambank exposure along Elevenmile Creek within the Darien Lakes State Park is the type locality of the Darien Center Submember. The entire 4-meter stratigraphic interval is well exposed here, and the major key beds can be easily recognized at the outcrop. We will use this stop to become familiar with the distinctive character of each of the various key beds discussed in the text. This locality provides an excellent opportunity to closely examine the vertical sequence of shell bed types and fossil assemblages characteristic of the Darien Center Submember.

Figure 11 displays the presence/absence macrofaunal data for this locality. This data reveals a nearly symmetric pattern, interpreted as reflecting a regressive-transgressive eustatic sealevel cycle. The higher faunal diversities of the transgressive half of the cycle probably reflect lower turbidity conditions, and are associated with more closely spaced and more condensed shell beds.

Near the center of the cyclic sequence is a prominent biostromal coral bed. Named the Darien Coral Bed, it attains its best development at this locality, and is dominated by the branching tabulate coral *Eridophyllum*. At Buffalo Creek (Stop 2) to the west, this same coral bed is represented only by widely scattered *Heliophylum* and *Cystiphylloides* corals. Along the outcrop belt to both the east and west of Elevenmile Creek, the Darien Coral Bed thins and becomes a horizon of scattered rugose corals before ceasing to be a recognizable marker bed (see Fig. 4 in the text).

NOTE: NO COLLECTING IS PERMITTED ON THE PROPERTY OF THE DARIEN LAKES STATE PARK.

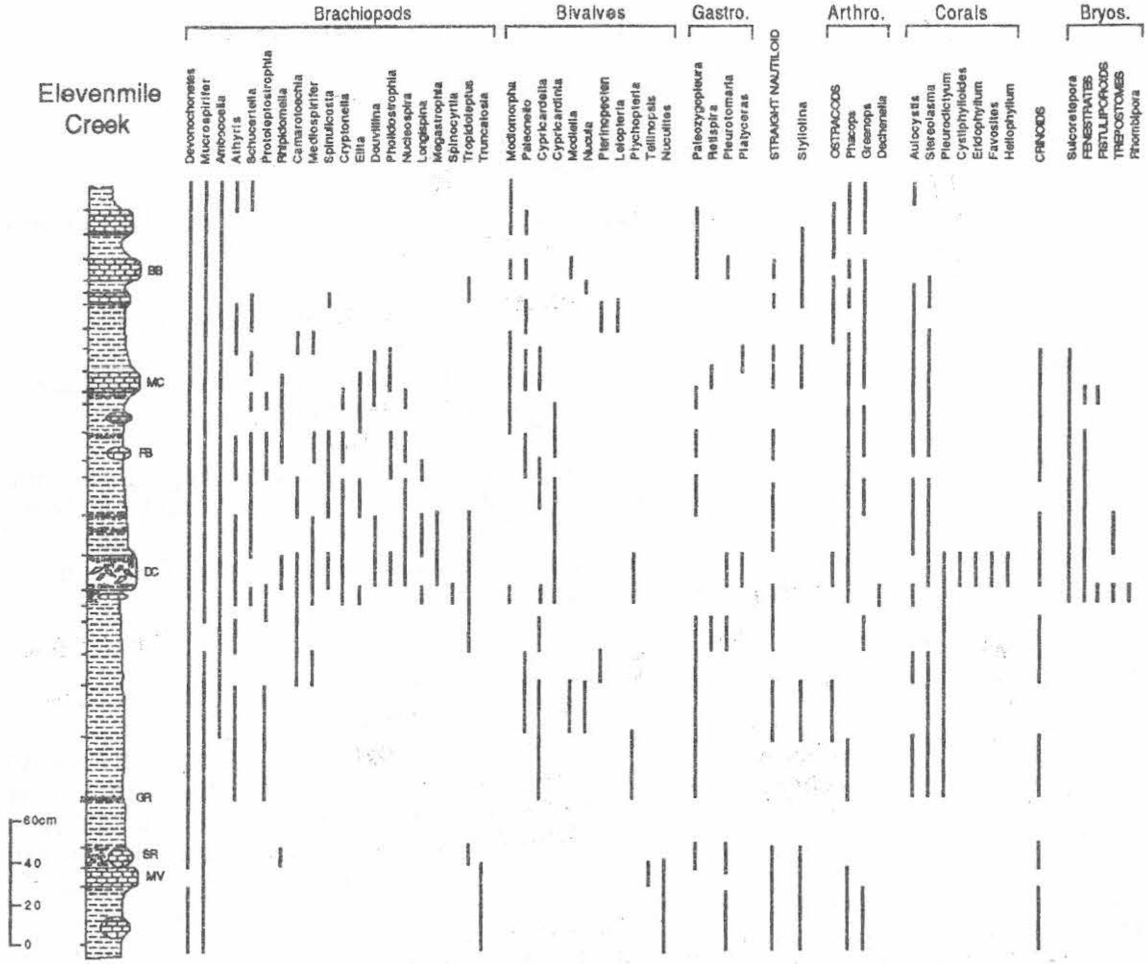

Figure 11. Stratigraphic column of Elevenmile Creek section with bed-by-bed presence/absence macrofaunal data. Note the general faunal symmetry of the interval reflecting a regressive-transgressive cycle, as well as the sharp faunal changes at the Girdle Road and Lakeview Beds. Important marker beds are indicated by letters as follows: MV) Mt. Vernon Bed, SR) Stolle Road Bed, LB) Lakeview Bed, MC) Murder Creek Bed, and BB) Bidwell Bed.

21.4	0.0	Turn left (south) on Harlow Road upon leaving Darien Lakes State Park.
21.9	0.5	Turn right (west) on Broadway (Rt. 20) toward Alden
25.1	3.2	At Alden turn left (south) onto Exchange Street (Rt. 239)
28.1	3.0	Turn right (west) onto Clinton Street (Rt. 354).
30.8	2.7	Cross Two Rod Road.

33.3	2.5	Turn left (south) onto Girdle Road.
33.6	0.3	Girdle Road Bridge over Buffalo Creek. Park along right side of road just before bridge. We will walk to south side of Buffalo Creek, walk down bank to the creek below and proceed downstream.

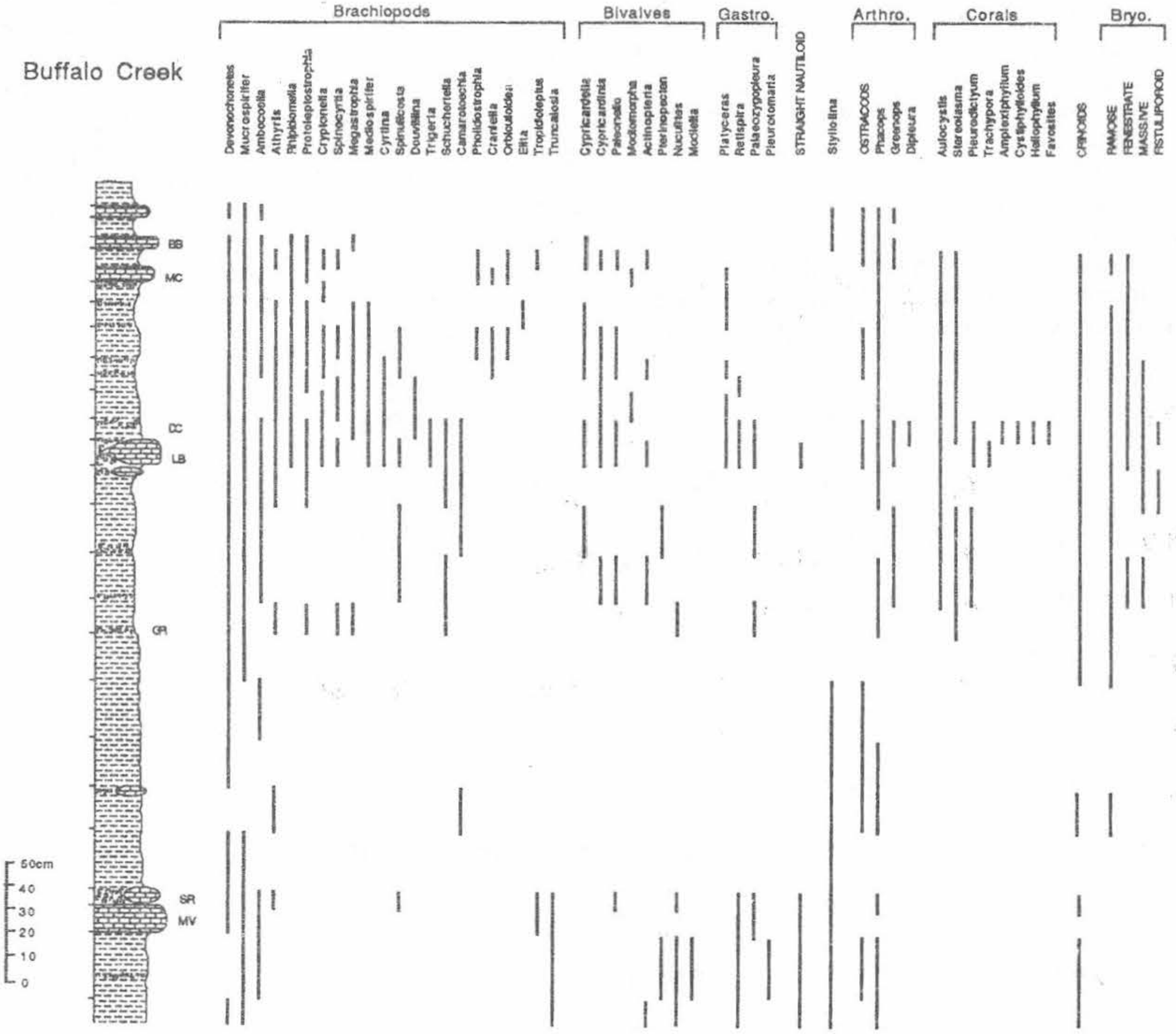

Figure 12. Stratigraphic column of Buffalo Creek section with bed-by-bed presence/absence macrofaunal data. Note the highly condensed transgressive portion of the cycle at this locality.

STOP 2 - BUFFALO CREEK AT GIRDLE ROAD BRIDGE

A continuous cut bank on the south side of Buffalo Creek to the west of the Girdle Road bridge exposes the entire Darien Center Submember for a distance of over 500 meters. At this locality, the Darien Center cycle is only 3 meters thick and the transgressive half is highly condensed. The presence/absence faunal data of Figure 12 shows this asymmetry and also reveals the sudden diversity changes associated with the traceable key beds. These distinctive marker horizons represent subcycle boundaries and are the basis for correlation across western and central New York State.

At the base of the Darien Center Submember is a peculiar discontinuity surface which is especially well displayed at this locality. This discontinuity is represented by the undulatory Stolle Road Bed which repeatedly separates from and merges with the underlying Mt. Vernon Bed defining a series of mudstone lenses of varying amplitude and width (see Figs. 8 and 9 in text). The mudstone lenses, or what I call "swells," are elongate features trending at a high angle to depositional strike. Dense shell layers dominated by the tiny brachiopod *Ambocoelia* occupy the broad flat "channel" areas between the swells. These shell layers extend up the flanks of the swells, becoming thinner and progressively losing fossil taxa. Over the tops of the swells the discontinuity is often represented only by a horizon of pyritic burrow tubes and pyrite nodules. The geometry of the swells and channels, and their approximately onshore-offshore orientation, suggest an analogy with modern sedimentary furrows produced by helical flow cells within episodically flowing bottom currents. This irregular erosion surface was formed during the early regressive phase of the Darien Center cycle, and may record an accentuated regressive pulse produced by a superimposed subcycle.

33.6	0.0	Continue south on Girdle Road
34.4	0.8	Turn right (west) on Bullis Road
38.9	4.5	Turn left (south) on Transit Road (Rt. 20/78)
39.2	0.3	Interchange with Rt. 400
39.7	0.5	Rt. 78 turns off. Continue on Transit Road
40.6	0.9	Bear right on Rt. 20
43.9	3.3	Cross Union road (Rt. 277)
45.5	1.6	Cross Southern Expressway (Rt. 219)
48.2	2.7	Pass under New York Thruway
48.6	0.4	Cross Rt. 62
50.4	1.8	Cross Rt. 75
56.2	5.8	Turn right (west) on South Creek Road after crossing Eighteenmile Creek
56.5	0.3	Pass through North Evans
57.4	0.9	Pass under railroad bridge
58.6	1.2	Cross Rt. 5

58.9	0.3	Turn right (northeast) on Lake Shore Road. After only a few hundred feet (before the bridge) turn right onto gravel drive and park in privately owned gravel parking area. Walk across the bridge over Eighteenmile Creek and then proceed toward the lake shore along the north bank. At the mouth of the creek walk north along the lake shore

STOP 3 - LAKE ERIE SHORE NORTH OF EIGHTEENMILE CREEK

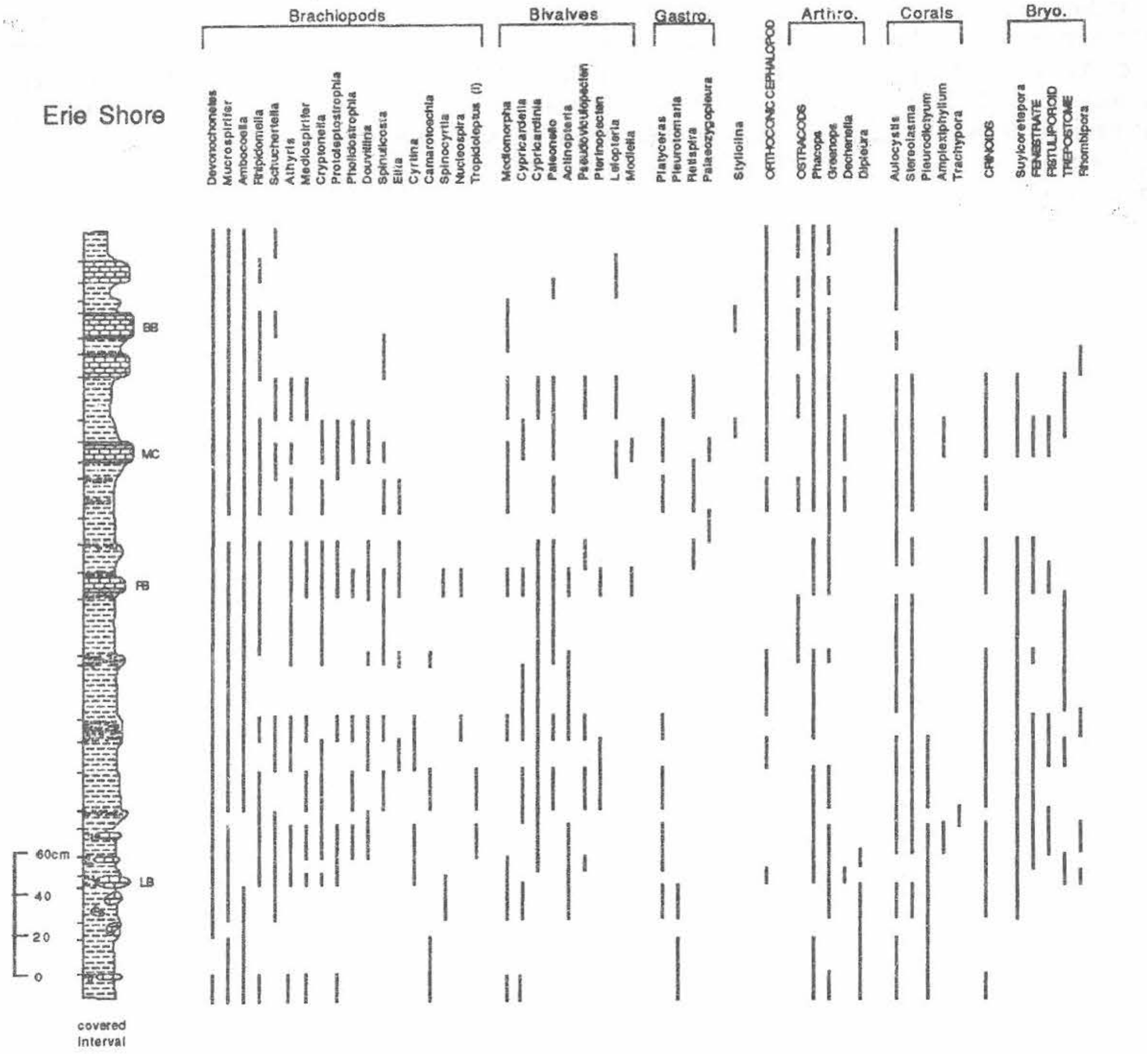

Figure 13. Stratigraphic column of Lake Erie shore section with bed-by-bed presence/absence macrofaunal data. Most of the regressive portion of the cycle is below the lake level at the Stop 3 locality.

This beautiful cliff exposure provides access to the upper transgressive half of the Darien Center Submember which alone is about 3 meters thick. The lower portion of the section is below lake level at this locality. The closely spaced shell beds can be easily examined and sampled here, and fossil collecting is excellent. Figure 13 shows the presence/absence faunal data for these lake shore cliffs.

The major key beds are easily recognized here. Especially well displayed at and near the lake level are the Lakeview Bed and the underlying shell beds containing abundant *Pleurodictyum* corals. Exposed bedding plane surfaces of these beds reveal well preserved *in situ* fossil assemblages on shell bed tops. Articulated and life position brachiopods are abundant, and complete trilobites and camerate crinoids can often be found. These fossils represent smothered epifaunal communities which had colonized winnowed shell hash layers. The shales overlying the shell beds are nearly barren of fossils and probably represent muds rapidly deposited by storm events. These muds were likely responsible for the preservation of the underlying shell beds by removing them from the sediment/water interface where taphonomic loss is great, and by stimulating early diagenetic pyritization and carbonate concretion formation.